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ON THE COVER Cascade Falls, Yosemite National Park Water conservation must play an increasingly significant role in water supply planning More efficient use of existing supplies, combined with new developments, will enable use to meet California's growing water demands This balanced appraoch will ensure adequate water supplies while allowing the combined use of some free-flowing streams for recreation and wildlife preservation

Department of
Water Resources

Bulletin 198-84

Water Conservation in California

July 1984

Gordon K. Van Vleck
Secretary for Resources

The Resources
Agency

George Deukmejian
Governor

State of
California

David N. Kennedy
Director

Department of
Water Resources

FOREWORD

Development of new sources of supply and conservation of existing water resources will both be necessary to meet projected water demands in the State. With the water resources of California becoming more costly and difficult to develop, it is imperative that water conservation be an integral part of water management. It is the Department's policy to work with public institutions and private organizations in the urban and agricultural sectors of the State to develop and implement voluntary and cost effective water conservation programs for stretching existing supplies.

In 1975, the Department conducted a major study of water conservation. The results were published in the first edition of Water Conservation in California. Bulletin 198, May 1976. Then, during the 1976-77 drought, the Department developed a number of programs to help water users respond to the emergency. As conditions returned to normal, we began programs to engender a gradual, but permanent change in patterns of water use in California. Today the Department carries out over two dozen different types of urban and agricultural water conservation programs including the development of information on costs and benefits of conservation measures.

In 1983 nearly every water utility in the State had some sort of conservation program. Growers, too, responding to higher water and power costs, are turning to more efficient irrigation systems.

This Bulletin reports on these current developments in water conservation in detail. The Department also has a number of shorter publications on various aspects of water conservation for those who have particular informational needs. These are available from:

Department of Water Resources
Office of Water Conservation
P.O. Box 388
Sacramento, CA 95802
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We hope that the Bulletin will increase understanding of the role of water conservation in statewide water resources management.

David N. Kennedy, Director
Department of Water Resources

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The California Water Commission serves as a policy advisory body to the Director of Water Resources on all California water resources matters. The nine-member citizen commission provides a water resources forum for the people of the State, acts as liaison between the legislative and executive branches of State Government, and coordinates Federal, State, and local water resources efforts.

CHAPTER I. INTRODUCTION

In the past decade, there has been a growing interest in water conservation. Water utilities have seen the cost of new supplies increase markedly as water use in their service areas has increased beyond the capacity of their local wells and reservoirs, forcing them to turn to more distant, more costly sources of water. Energy costs have also risen, increasing utilities' operating costs. Consequently, many utility managers have become interested in more efficient use of water.

Agriculture has also run into difficulties with water. In many parts of California, growers' pumping costs have risen sharply as a result of falling ground water levels and increasing energy costs. Water agencies are finding it harder to get more supplies of surface water because the more favorable reservoir sites were used in the early days of water development; water wholesalers, such as the Department of Water Resources (DWR) and the Bureau of Reclamation, have for a variety of reasons encountered delays in efforts to enlarge their water projects.

Conservation programs can also be an economical way of maintaining water quality, because they reduce the amount of sewage that has to be treated, cutting treatment costs and reducing the amount of effluent discharged to water courses.

Savings From Conservation

In order to plan future water development properly, the effect of conservation on future water use must be considered. The way in which conservation programs will affect the supply and use of water is not always obvious. Water does not disappear when it is used; in most cases, some of it can be recovered and used again. Thus, a reduction in water use will not always result in a real saving of water.

Water is lost to further use when it flows to the sea or a salt lake, seeps to a body of saline ground water, or passes into the atmosphere. A reduction in these losses is a water supply saving. Whether a particular conservation measure will result in a water supply saving depends on where the water is being used. Just over half of the water delivered by urban water utilities in California is used indoors for washing and for flushing toilets. Virtually all of this water is collected by sewers, treated, and then discharged to a river or the sea. In areas where sewage effluent is discharged to rivers and becomes part of the downstream supply, a reduction in indoor use will not be a water supply saving since it will reduce the supply of downstream water users; these users will have to make up their supply by increased diversions from other sources. However, when the sewage effluent is discharged to the sea, or to a river or an estuary when there is no downstream use, reductions in indoor use will be water supply savings since no downstream users will be affected.

Much of the water used for watering lawns and gardens is lost to the atmosphere. Reductions in this consumptive use will be water supply savings. Some of the water used on gardens runs off and eventually flows into storm sewers. Reductions in this runoff of excess water will be water supply savings only when water from the storm sewers is discharged to the sea or is otherwise lost to further use.

When water is used for irrigation, some is lost to the atmosphere as transpiration from the crop and evaporation from the soil surface, some runs off the end of the field, and some seeps down into the ground. In most cases, the water that runs off the end of the field and seeps into the ground is available for use elsewhere. Most improvements in irrigation practice do not affect the amount of water lost to the atmosphere. Consequently, reductions in applications of irrigation water will not generally result in water supply savings. Real savings in the amount of water used in agriculture can be achieved only by changes in the crops grown in the State and improvements in irrigation practice in places where runoff and seepage goes to the sea, a salt lake, a body of saline ground water, or is otherwise unusable.

The Department of Water Resources has recently examined the way in which the growth in water use in the State would be affected by conservation. This study was part of a major review of water use and water supply in California, reported in The California Water Plan: Projected Use of Water Supplies to 2010, DWR Bulletin 160-83. In this study, the extent to which water utilities, householders, and growers could adopt the conservation measures described in this Bulletin was assessed and the resulting decrease in additional water needs were estimated. As a result of conservation by urban water users, decreases in additional demands of nearly 1.0 million acre-feet/year are expected to occur by 2010; conservation in agriculture is expected to result in decreases in additional needs of about 0.6 million acre-feet/year by 2010. The reduction resulting from conservation in agriculture is relatively small because much of the water applied in irrigation is reused by growers further downstream. Nearly 0.5 million acre-feet of the agricultural savings could occur in Imperial Valley where excess applied water flows to the Salton Sea. In contrast, larger reductions result from conservation by urban water users because most of the population in California is in the coastal basins where much of the sewage effluent is not reused, but discharged to the sea.

Even with conservation, water use in California will continue to rise. As the State's population continues to increase and as our ground water basins continue to be overdrafted, water use in the State is expected to increase by 3.5 million acre-feet/year by year 2010.

However, water conservation will curtail the growth in water use: without water conservation, it is estimated that water use would increase by a further 1.6 million acre-feet/year by year 2010.

Conservation Programs

Many water utilities began conservation programs in the early 1970s. Several utilities distributed kits containing water-saving devices to their customers. Others had public information campaigns; some began education programs in which they distributed educational materials on water to schools in their service areas. Some utilities began inspecting their mains with listening equipment in order to detect leaks from their distribution systems.

When the California drought began in 1976, utilities expanded their conservation efforts. Most of the new programs were intended to bring about an immediate reduction in water use. Some utilities rationed water or passed regulations prohibiting excessive water use. Many more gave displacement bottles and shower flow restrictors to their customers. After the drought, utilities returned to programs aimed at bringing about a permanent change in their customers' water-using habits. Most of the water utilities in the state now regard water conservation as an integral part of their operations. Chapter II of this Bulletin gives an account of the latest developments in urban water conservation.

In agriculture, water use is the result of growers' business decisions. In areas where water is expensive, growers have always had incentives to use water carefully. These incentives have increased in recent years as the cost of pumping has risen and new supplies of water are becoming harder to obtain. Growers are now grading their fields with laser-controlled earthmoving equipment. By using this equipment, fields can be graded very accurately, and water applications can be kept to a minimum. Other innovations such as linear-move sprinklers have also become popular in recent years.

Growers can reduce water applications by scheduling their irrigations so that the amount of water applied in each irrigation exactly matches the needs of the crop. An increasing number of consultants offer scheduling services to growers. Several irrigation districts now offer scheduling services. Chapter III describes the latest developments in irrigation management.

The State's Role

The State began to take an interest in water conservation in the early 1970s. Most of California's more favorable reservoir sites had been developed in the 1950s and 1960s with major construction by local agencies, and for the Central valley Project and the State Water Project. Environmental concerns and the high cost of developing water from the remaining, less productive sites meant that water supply agencies could no longer continue to respond to increasing water use only by building new reservoirs. In 1975, the Department of Water Resources began a major study of water conservaiton; the results of this study were published in the original edition of Water Conservation in California, Bulletin 198, May 1976.

When the drought began in 1976, the Department began several programs to help water utilities and the public respond to the emergency. The Department produced public information materials and made them available to water utilities for distribution. As the drought went on, the Department held a number of conferences on water conservation. The Department also arranged exchanges of water so that agencies with surplus water could allow utilities facing water shortages to use some of their supplies.

After the drought, the Department began a number of programs to develop more information on water conservation. Many water utilities had found that they could reduce water use by giving kits containing water-saving devices to their customers. To help water utilities determine the best way of distributing these kits, the Department made a pilot study in which it distributed kits in a number of different ways. Experience gained in this study formed the basis of the Department's own kit program in which it mailed kits to households in areas with water supply problems. The Department is currently providing grants to water utilities to conduct leak detection programs. The Department is also continuing to develop public information materials on water conservation for use by utilities.

Other programs are aimed at helping growers use water efficiently. An irrigation scheduling guide has been published, and four mobile laboratories have been equipped to evaluate growers' irrigation systems. A research and development project has been started that will determine better ways of providing irrigation scheduling information to growers. As noted earlier in this Chapter, it is recognized that improved irrigation efficiency does not necessarily mean a reduction is the need for water supply on a regional basis. Nevertheless, savings when and where they do occur are important as are the other benefits which accrue to the grower. These water conservation programs are described in more detail in Chapters II and III.

The Future

Cooperation among State, Federal, and local agencies, and the private sector will continue to foster water conservation over the long term. We need to improve irrigation management, and quantify more accurately the effectiveness of urban and agricultural water conservation measures.

Continued information sharing and education will also help us to meet our conservation goal. The State will continue to assist urban agencies with their conservation programs, particularly in areas where water conservation yields water supply savings.

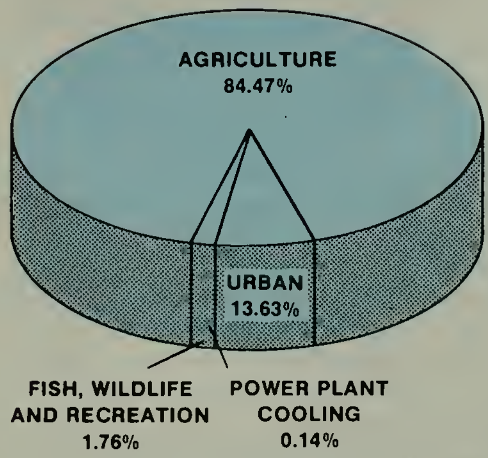
Through these actions we will help assure that our water resources are managed in a way that will result in the greatest long-term benefit to the people of California.

CHAPTER II
URBAN WATER CONSERVATION

California's 24 million residents make it the most populous state in the nation. Most of these people live in cities and towns. Water use by these Californians, in homes and gardens, in the businesses and factories where they work, in the parks where they play, is called urban water use. After agricultural water use, it accounts for the largest share of the state's applied water--about 14 percent of the total. This is nearly 6 million acre-feet/year. Figure 1 shows how water use in California is divided.

The population in California is not evenly distributed. More than half the people live in just five of the 58 counties. Tiny Alpine County has slightly over 1,000 residents, and Los Angeles County well over 7 million. Thus, a few densely populated areas, including the south coastal plain, the San Francisco Bay area, and a few major Central Valley cities, account for most of California's urban water use.

Efficient use of urban water supplies has become an important consideration for several reasons. For one thing, less costly water supply developments usually have been constructed first, and the high cost of additional development has prompted better management of existing supplies. In addition, rapid increases in the cost of energy have provided incentives to reduce the pumping, treatment, and heating of water whenever reasonable. Finally, the expense of sewage treatment plant construction or expansion, and the considerable time necessary to complete such projects, have prompted communities to promote the reduction of indoor per-capita use, thereby reducing water flows and enabling existing facilities to satisfy needs for a longer period.



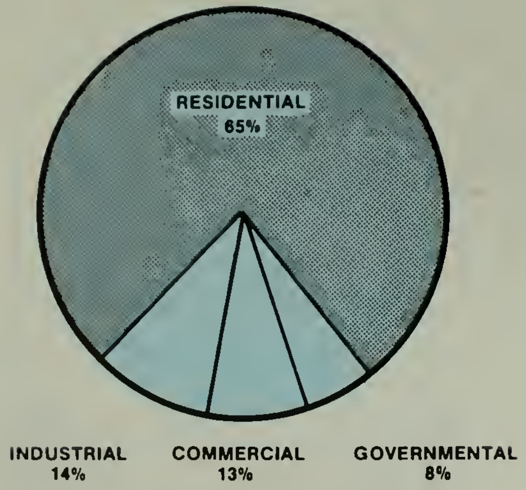
	1,000 ACRE FEET
Urban	5,750
Agriculture	35,640
Power Plant Cooling	60
Fish, Wildlife and Recreation	740
STATE TOTAL	42,190

Figure 1. Statewide Applied Water by Type of Use, 1980

Urban Water Use

Urban water use can be divided into several categories, including residential, commercial, governmental, and industrial. Residential use, in and around homes and apartments, accounts for the largest share of urban water use. Next is industrial water use, for cooling, processing, and manufacturing. Commercial use includes use by retail businesses, laundries, office buildings, hotels, restaurants, private cemeteries, and golf courses. The smallest category is governmental, including water used by schools, prisons, public hospitals, military installations, parks, and fire departments. Figure 2 shows the categories of urban applied water use.

Urban water uses can also be categorized according to whether the water is later available for reuse. In inland areas



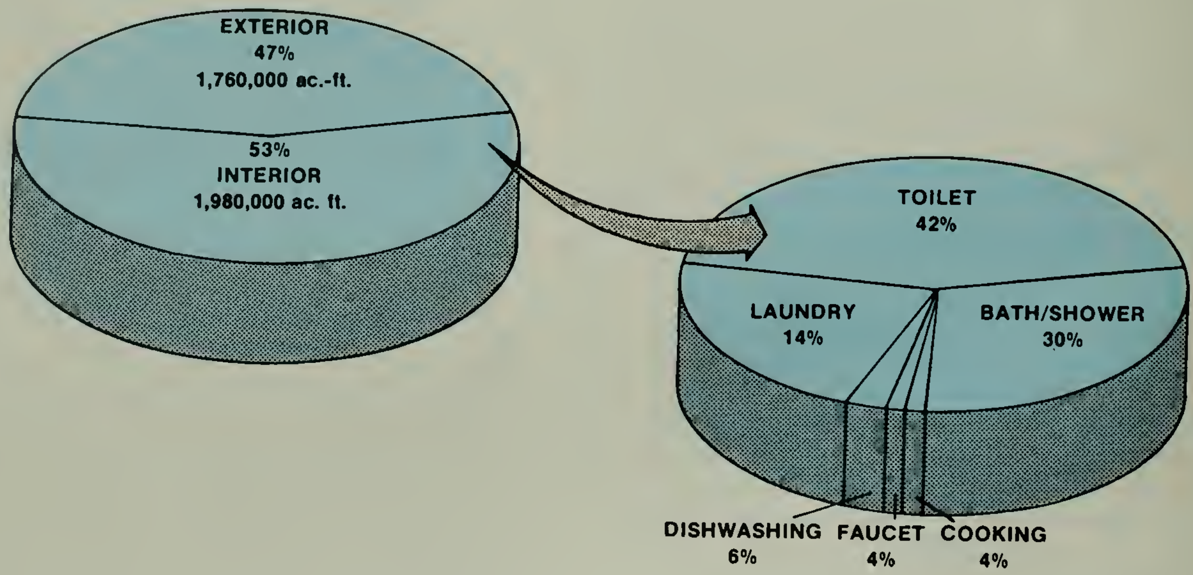
	1000 ACRE-FEET
Residential	3,740
Industrial	800
Commercial	750
Governmental	480
STATE TOTAL	5,750

Figure 2. Urban Applied Water Use, 1980

when a toilet is flushed, for instance, the effluent can be treated and discharged to enhance stream flow, it can be used to irrigate turfgrass, or it can be reused in some other manner. This type of water use, which makes water available for reuse, is called nonconsumptive use. Other water uses truly consume water, and do not make it available to be reused directly. Examples of consumptive use include evaporation from the soil, from plant surfaces, and from impervious surfaces, and transpiration of water by plants. Some consumptive use also occurs indoors, when water evaporates during cooling, cleaning, or food preparation processes.

Residential Water Use

Residential water use includes water used indoors and outdoors. The largest share is used for landscape irrigation,



	1000 ACRE FEET
Toilet	830
Bath/Shower	590
Laundry	280
Dishwashing	120
Faucet	80
Cooking	80

Figure 3. Residential Water Use, 1980

* Column totals do not match pie chart totals because of independent rounding

particularly in detached single-family dwellings. Toilet flushing accounts for the largest share of indoor use, followed by showers and baths, laundry, cooking, and kitchen use. Figure 3 depicts various residential water uses.

Water consumption varies by the type of dwelling unit. Apartment and condominium residences usually have a lower per-capita landscape usage than do single-family residences because there is less planted area per resident, and maintenance services are frequently centralized and more efficient.

Commercial Water Use

Commercial water users, such as retail establishments, restaurants, and banks, use water in a variety of ways, mainly for landscaping and indoor sanitation. Individual customers such as laundries and car washes can use large amounts. It is difficult to accurately describe this user class because of the lack of accurate data. Water use data are often aggregated by water meter size, not by types of use. This makes it difficult to separate commercial use from use in apartment houses and condominiums.

Industrial Water Use

Industrial water use accounts for about 15 percent of all urban uses. Although this is a small part of the total in California, individual industries or firms often account for significant usage within a region. In the North Coastal area, for instance, industrial water use by lumber mills and pulp mills represents a large proportion of the total urban applied water use.

Use among industrial firms varies greatly, particularly since passage of the Federal Water Pollution Control Act of 1972. This act required that where industrial wastes are collected and treated by public agencies, the industry must repay all costs properly allocated to it, based on the volume and character of the wastes. As a result, many industrial firms have undertaken water conservation programs to reduce waste flow and thereby reduce costs.

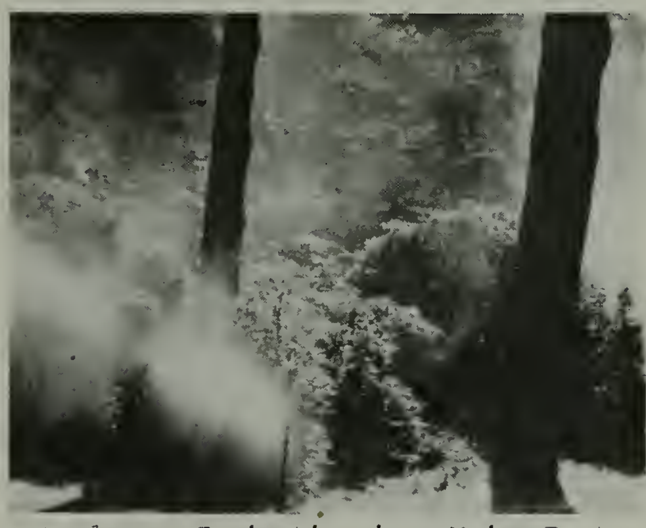
Industrial use and conservation is discussed in greater detail in DWR Bulletin 124-3, Water Use by Manufacturing Industries in California, 1979, May 1982.

Governmental Water Use

Government is the custodian of large landscaped areas in California, and a large part of governmental water use is for landscape irrigation. Parks under the care of cities, counties and the State are the largest landscape element, followed by road and freeway landscapes, which are primarily under State control. Schools, public cemeteries and government offices are also significant landscape water uses. Military bases account for substantial landscape water demand as well. A large part of interior governmental water use is for flushing toilets.

Factors Influencing Urban Water Use

Residential water use is influenced by several factors, including climate, household income, price, fashion, and conservation awareness. In hot, dry areas such as the San Joaquin Valley and



Landscape Irrigation is a Major Part of Governmental Water Use.

Southern California, high vegetative water demand is responsible for high residential water use for landscaping, whereas the higher humidities and milder temperatures of central and northern coastal areas result in lower residential exterior water use.

Although residential water use accounts for the largest share of urban water use statewide, this is not true in every community. In the North Coastal area residential use is very low compared to usage in the pulp and paper industries.

Seasonal differences throughout the State also influence water consumption, especially for landscape and recreational uses in hotter, drier areas. Seasonal fluctuation of per-capita water use for three cities is shown in Table 1. Urban water use is greater during summer months because residential and other landscapes are irrigated most extensively during the hotter months. Consumptive use for swimming pools and other recreational settings is greatest during summer. California's fruit-canning industry, a very substantial urban water user, is most active in summer and fall.

Total urban water use has risen continuously, outpacing population growth. Historical data reveal a steady increase in per-capita water use since about 1920, when records were initiated. The rate of increase became even greater after World War II. The trend in per-capita water use leveled off around 1970. The shift in percentage of single family homes as compared to multifamily is one reason for this, since apartment residents use less landscape water on a per capita basis. There was a sharp drop in per capita water use during the 1976-77 drought. Use in most areas has increased slightly each year since the drought, in some cases equaling or surpassing predrought use. Average per-capita water use for the 20-year period between 1960 and 1980 is illustrated in Figure 4.

Effects of Water Conservation

Water Conservation and Sewage Treatment

Most water used indoors is collected and treated as sewage. Municipal sewage is collected and treated to protect water supplies and prevent disease. Most sewage treatment currently involves two stages: a primary stage to remove solids and pathogens by sedimentation, and a secondary stage to remove oxygen-demanding materials and further reduce pathogens. Primary and secondary treatment are energy- and material-intensive processes, which have increased in cost over time due to increasing energy and chemical costs.

Table 1. Water Use for Three Cities, 1978-1980

City	Water Use		
	Average	January	July
	(gallons per capita per day)		
San Francisco	124	111	130
Sacramento	291	164	468
Los Angeles	171	124	218

Source: California Department of Water Resources. Urban Water Use in California, Bulletin 166-3. 1983.

The figures show use of water delivered by water supplier; does not include self-supplied water.

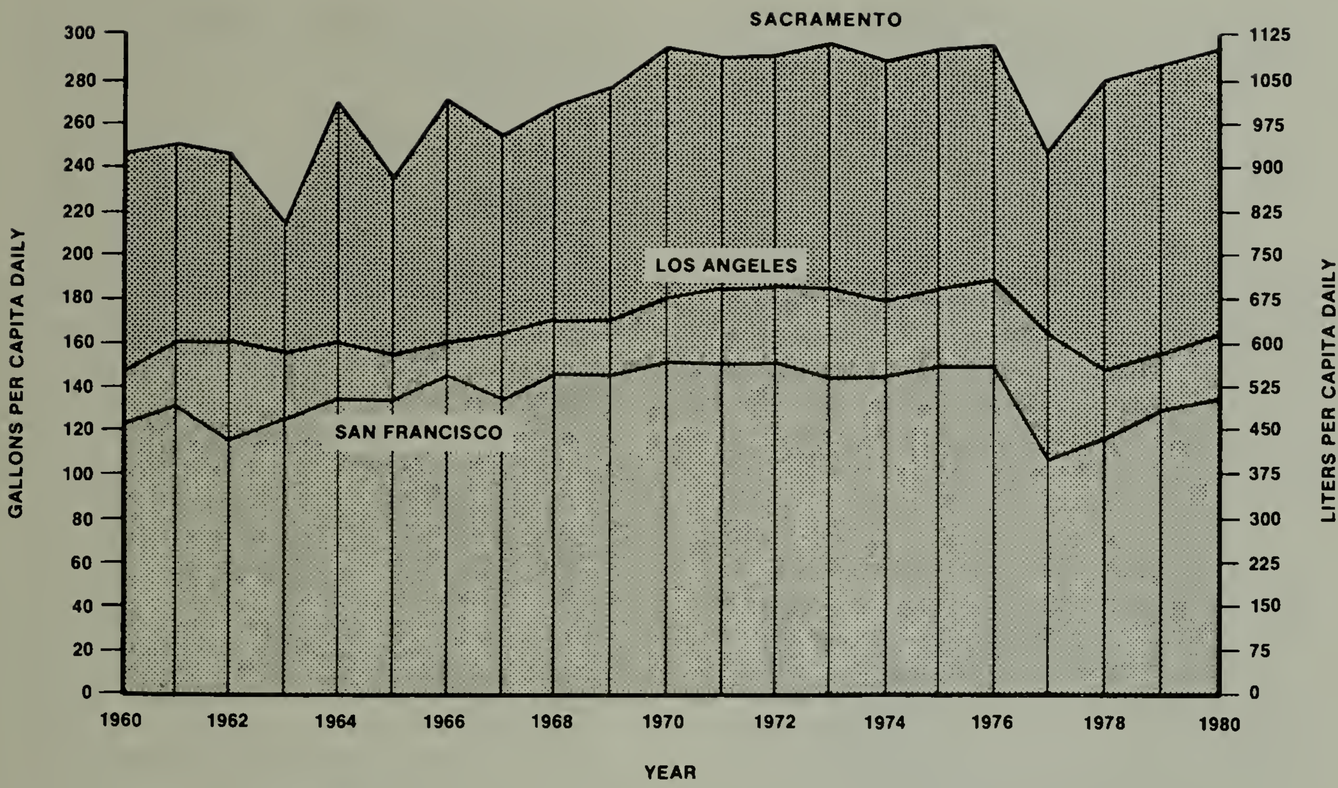


Figure 4. Average Per-Capita Water Use, 1960-1980

Reduction in interior water use will result in reductions in sewage flow. This reduction can have many effects, both positive and negative, on the operation of the sewer system. To determine the effects of conservation on waste water treatment, the Department prepared a study for the Environmental Protection Agency in 1980. The study, Effects of Water Conservation-Induced Wastewater Flow Reduction, found that during the 1976-77 drought, treatment plants had an increase in biochemical oxygen demand and suspended-solids concentrations of 15 to 40 percent. Waste will also remain in sewer lines for a longer period of time due to the lower flow velocity. Some solids will settle in sewer systems, and it may be necessary to add chemical oxidants to sewer systems for odor control. In some cases, the solids content of influent reaching the treatment plant may decrease. This is not an expected result of water conservation, but it may occur because some solids settle and decompose in the sewer lines. Another cause could be less use of water-consuming garbage disposals.

Handling a smaller volume of more concentrated influent requires certain changes in operation and maintenance of the treatment plant. Less energy is needed because there is less influent to pump and transport. Some processes, such as chlorine disinfection and sulfur dioxide dechlorination, require a smaller quantity of chemicals. However, operational problems were encountered by treatment plants during the drought. Additional chlorine was needed to control odors and the growth of filamentous bacteria. Larger quantities of coagulants were needed. Overall operation and maintenance costs were reduced very slightly with individual plant cost changes ranging from a decrease of 5 percent to an increase of 4 percent.

The most significant effect of water conservation on sewer systems is the reduced need for system construction or expansion. Sewer systems are very expensive to build and even small reductions in size can yield large cost savings. If lower per capita water use can be guaranteed, flows can be reduced and pipes can be selected one or two sizes smaller, yielding about a 7 percent reduction in costs. In the treatment plant itself, headworks, primary and secondary clarifiers, effluent chlorination facilities, and effluent outfall may all be reduced in size. The cost of plant expansion may be reduced as much as 20 percent. The capital costs of new plants may be as much as 8 percent lower.

Water conservation may have a small adverse effect on water reclamation if the water is reused directly rather than being discharged to a waterway. The salt concentration of effluent is likely to increase as a result of water conservation efforts. Domestic use typically causes a salt pick-up of about 300 milligrams per liter (mg/L) in the water used. The incremental increase in total dissolved solids (TDS) attributable to reductions in indoor use ranges from about 30 mg/L at 10 percent reduction in indoor use to about 160 mg/L at 35 percent reduction in indoor use. This increase in salt concentration might make the reused water less acceptable for the irrigation of salt-sensitive crops such as citrus and deciduous orchards. This problem can often be solved by blending the treated waste water with another water supply. Crops with greater salt tolerance, such as cotton and barley, would probably not be affected. The increase in TDS would probably not affect usefulness of the effluent for landscape irrigation; turfgrasses are relatively salt tolerant.

A reduction in the water supply available for reclamation due to an increase in water conservation is not expected to be a significant problem because only a fraction of the waste water produced in California is reclaimed directly. Much more water is discharged to waterways and used again downstream.

Water Conservation and Energy Conservation

Energy is required to transport water, to pump supplies from aqueduct to user, to operate pre-treatment and sewage treatment plants, to pump ground water supplies, and to heat water for domestic, commercial, and industrial uses.

The two largest energy users among these operations are transport of water to urban areas and heating of water after delivery to the customer. Still, significant amounts of energy are used in pre-treatment, local distribution, and post-treatment. Local water distribution requires an average of 200 kilowatt hours (kWh) per acre-foot. According to the report cited above, Effects of Water Conservation-Induced Wastewater Flow Reduction, local pre-treatment requires about 35 kWh per acre-foot, and post-treatment takes another 100 kWh. The sum of energy uses for these 3 steps is about 335 kWh of electricity for each acre-foot used. Energy used to deliver the water to the local water agency and energy to heat water are not included in this total. Clearly, the conservation of urban water supplies can result in very significant energy savings as well.

Water Conservation and Water Supply Savings

As we have seen above, a water conservation measure such as the use of a low-flow showerhead may result in energy conservation and a reduction in sewage treatment costs, because less water is used. However, since this is a nonconsumptive use of water, any amount used may be available for reuse. If the treated effluent is reclaimed or re-enters a waterway where it will be available for use downstream then there has not been a water supply savings, but merely a reduction in use. If the treated sewage is discharged to the ocean, where no further reuse could occur, then there is a water savings to be achieved by using less. Likewise, if consumptive uses of water such as evaporation and transpiration are reduced, then the result is a water supply savings. This is a very important concept. Conserving water is often beneficial in terms of energy savings and cost reductions, but does not always yield additional water for other purposes.

WATER CONSERVATION MEASURES

Residential Water Conservation

Domestic use, which accounts for some 62 percent of urban water use, is sometimes inefficient. Water-using fixtures and appliances have often been designed with little regard for efficient water use. Opportunities exist for reducing water use without altering lifestyle significantly. Figure 5 compares residential per capita water use in a home that has standard fixtures and landscaping with the Department's estimate of per capita water use in a home that has water-conserving fixtures and landscaping.

Residential Interior Use

Toilet Flushing. The largest use of water inside the home is for toilet flushing, and the development of the toilet in the United States provides a good example of how relative abundance and low cost at the time resulted in a design undesirable for present day conditions. The turn-of-the-century water closet was similar to those in use today, but the tank was mounted high on the wall, and the toilet was flushed by means of a pull chain. The high velocity of the water traveling downward several feet from the tank to the bowl provided a powerful flush with only 2 to 2.5 gallons of water. Later the tank was moved down to waist height. The water gained less velocity traveling from this lower tank to the bowl, and the flush volume was increased two or three fold. This is the most common type of toilet used in residences today. A standard toilet of this type uses 5 to 7 gallons per flush. A further development is the one-piece toilet, in which the tank and bowl are molded together and the drop from tank to bowl is even shorter.

A water-saving variation of the standard toilet is the shallow-trap toilet, shown in Figure 6. Similar in appearance and operation to standard toilets, shallow-trap models hold less water in the bowl and trap so the siphon action which flushes out the bowl can occur with less water. These toilets use 3 to 4 gallons per flush. As concern over efficient use of water increases, shallow trap

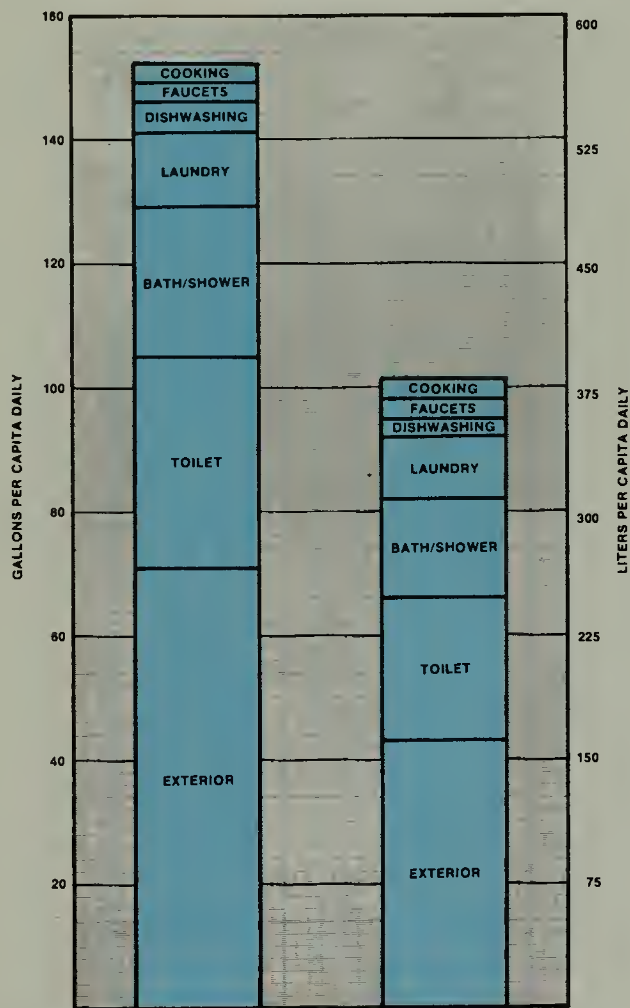


Figure 5. A Comparison of Residential Per-Capital Water Use: Standard Fixtures and Landscaping vs. Water-Conserving

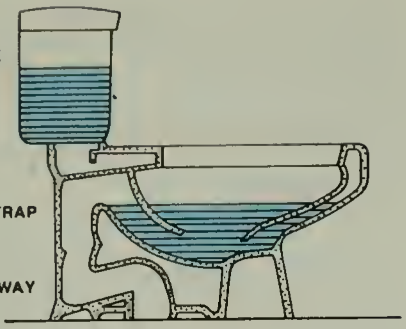


Figure 6. Water-Conserving Shallow-Trap Toilet

toilets are becoming the standard for residential installation. These water-saving models usually cost no more than regular toilets.

While shallow-trap toilets are a great improvement over standard toilets, they are by no means the ultimate in design. Some manufactures have been able to reduce flush volume even more. Several water closets are available that use between 2 and 3 gallons of water per flush. There are even a few fixtures on the market that operate quite well with only 1 to 1.5 gallons. In some cases, this very low flush volume is achieved by reducing the trap seal depth and the amount of water held in the toilet bowl, and in these respects the fixtures do not comply with some U.S. plumbing codes. Still, such fixtures demonstrate the efficiency that can be attained with a tank-type toilet.

Advantages of these very low flush toilets include a reasonable level of consumer satisfaction, no required change in lifestyle, no need for electrical energy to operate the fixture, low water use, and low cost compared to other alternative systems. The disadvantages are high price compared to standard toilets and, in some cases, noncompliance with current codes and standards.

A system widely used in special applications, and gaining acceptance in water-short areas, is the compressed-air toilet. This type of fixture flushes wastes into a small evacuation chamber using 1/2 gallon of water. Compressed air is released into this chamber, forcing the contents out through the discharge line to the sewer. Individual systems have been in operation as long as 15 years, confirming their dependability.

The great advantages of compressed-air toilets include consumer acceptance due to similarity to traditional toilets and remarkably low water use. Disadvantages include need for electrical energy to run the system, periodic maintenance needs, and high initial cost.

It is not necessary to use potable water to flush the toilet at all. Some alternative systems are based on the premise that household graywater will serve as well. Graywater recycling systems that collect laundry and bathing water for toilet flushing are now available, although their use is still largely experimental. The water undergoes treatment consisting of sedimentation, filtration, and chlorination. It is stored in a holding tank and pumped through a recycle water line to the toilet when needed. If bathing and laundry water use is of insufficient quantity for toilet flushing, fresh makeup water is added automatically. Monitored usage of the system has shown freshwater makeup needs to be between 0 and 0.6 gallons per person per day.

Advantages of this type of system include virtually no use of fresh water and ability to use a toilet of familiar design. At present, there are several disadvantages. The system is costly and difficult to install in existing dwellings and may create potential health problems. It requires periodic maintenance, electrical energy, and chemicals (chlorine). More frequent toilet cleaning may be necessary, and there may be occasional odors or coloration in the water. If system costs can be reduced and the disadvantages can be overcome,

Table 2. Toilet Alternatives -- A Comparison

Type of Toilet	Fresh Water Use per Flush	Energy Use per Flush	Cost For Two-Bath Home	Cost Over Standard	Cost for O&M[a]
	(gallons)	(kWh)	-----(dollars)------		($/year)
1. Standard	5-7	0	300	--	0
2. Shallow Trap	3.5[b]	0	300	0	0
3. European	1.6	0	700	400	0
4. Compressed Air	0.5	0.0016	1000	700	c
5. Graywater	0	.017	3500	3200	50

a Operation and Maintenance
b Maximum allowed in California
c Requires periodic user maintenance

use of these systems could reduce domestic water use considerably.

Table 2, compiled from several sources, compares toilet alternatives.

Bathing and Showering. The second largest use of water inside the home, after toilet flushing, is for bathing and showering. Once again, there are opportunities for reductions in this sector of water use.

By the early part of the 20th century, people were placing greater importance on cleanliness. Both water and the energy to heat it were relatively inexpensive, and Americans used both in greater quantities. As showering became more popular than bathing, a fixed volume of water in the tub was replaced with a stream of heated water, resulting in even greater water use.

The standard showerhead available before the advent of water-conserving models delivered up to 5 to 10 gallons of water per minute, or more, at water pressures between 15 and 80 pounds per square inch gauge (psig). Preliminary results of

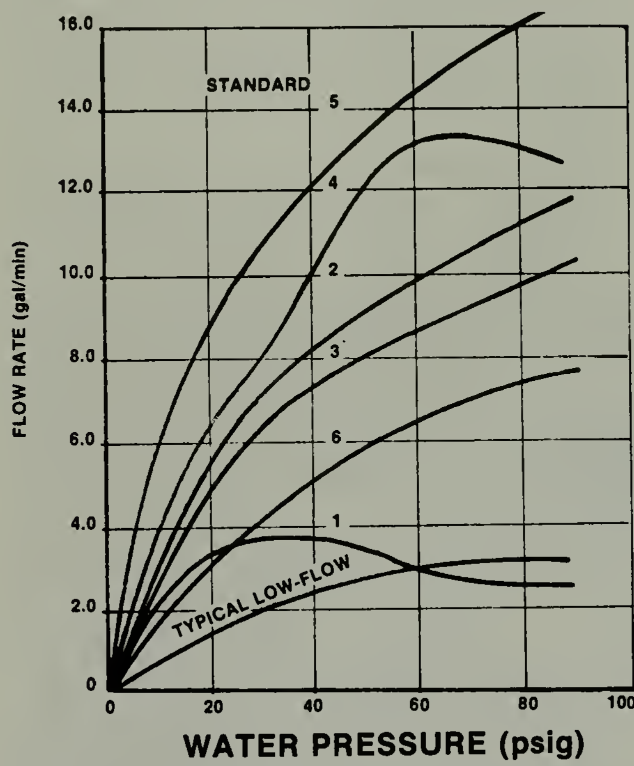


Figure 7. Comparison of Standard and Low-Flow Showerheads
(From DWR Bulletin 191)

recent studies suggest that the flow rate in actual use may be less. Most of the efforts to reduce bath and shower water use have been aimed at reducing the flow of showerheads while maintaining an acceptable spray pattern. These efforts have been quite successful. Water-conserving showerheads available today provide acceptable showers at flow rates between 1.5 and 3 gallons per minute (gpm).

Figure 7 compares standard and water-conserving showerheads.

A highly significant side effect of reducing shower flow is a reduction in energy use because less heated water is used. Sometimes this energy savings is the primary reason for use of water-efficient showerheads.

By using a water-conserving showerhead rather than a standard one, a typical household can accrue significant savings over time. A family of four, showering daily, may conserve up to 28,000 gallons of water and the energy equivalent of nearly 3 barrels of oil in a year's time.

A major field study being conducted for the U. S. Department of Housing and Urban Development showed potential water savings from low-flow showerheads to be much lower than previously believed. Initial findings show that the average flow from standard showerheads tested in actual households is much lower than the flow measured by the Department and others in laboratory tests. If these findings are confirmed, a reexamination of the water and energy savings available from low-flow showerheads will be in order.

Still greater reductions in shower water use can be achieved in two ways: by further reducing the showerhead flow rate, or by reducing the length of time the water is flowing. Additional reductions in flow rate have been accomplished by using an air compressor to mix air with the water to create a forceful effect with about 0.5 gpm. A disadvantage is the need for additional electrical energy to operate the system (although some energy use is avoided by reducing hot water use).

Other alternatives that reduce the duration of the shower flow are available. One of the simplest is a small on-off valve, which can be inserted in the water line between the shower arm and shower head. The valve allows the user to turn the flow off while lathering without changing the temperature setting of the shower water. Other types of valves that can be turned off without changing the temperature setting can be used for the same purpose. One that has the potential for even greater water savings is the thermostatically controlled mixing valve. This valve has one knob to adjust water temperature and another to adjust flow rate. Water coming from the fixture is kept at the set temperature automatically by means of a temperature-sensitive bimetallic spring. The spring moves a mechanism in the valve to keep the temperature constant. Such valves could reduce the time spent waiting for the shower water temperature to stabilize.

Clothes Washing. Another use of water in the home is for laundering clothes. Because this accounts for only about 14 percent of interior residential use, less attention has been paid to the laundry than to the toilet or shower. Still, improvements in efficiency are being attained. Research by the Department indicates that of clothes washing machine manufacturers representing 90 percent of the U. S. market, those selling to 60 percent of the market have redesigned their 1980 machines to use from 10 to 30 percent less water than 1975 models. Other manufacturers have not substantially changed their water consumption design, but nearly all clothes washing machines now include a fill-level control, which allows the user to regulate the water level according to the size of the load.

Additional water savings can be achieved in the laundry by reusing some of the washwater for the next load. This is accomplished by diverting the used washwater to a service sink or, in some models, to a built-in holding reservoir. After the solids have settled out, about 17 gallons of this washwater can be reused for the next load of laundry. This results in savings of water, energy, and detergent - if two loads of laundry are washed consecutively.

Dish Washing. About 6 percent of interior residential water use is for washing dishes. Research by the Department shows that automatic dish washing machines, like clothes washing machines, are becoming more water-efficient. Since 1975, manufacturers representing 73 percent of the market have reduced water use by an average of 33 percent. The remaining 27 percent of the market has not yet reduced water use.

Faucets. Relatively little water use in the home is associated with faucet use, but even here some water saving potential exists. Standard kitchen and lavatory faucets can deliver 5 gpm at full flow. Since most faucet use requires a forceful stream of water but not a large volume, it is only necessary to produce a stream of water which appears to have a high flow rate. Low-flow faucets deliver a satisfactory stream of water with a maximum flow rate of 2.75 gpm. This is usually accomplished with an aerator, a fitting that attaches to the end of a threaded faucet spout and incorporates tiny air bubbles into the stream of water. Aerators also reduce splashing. They have become the standard on all new faucets sold.

Other Modifications. Domestic interior water use in existing dwellings can be reduced significantly by modifying standard fixtures. Toilets and showerheads may be retrofitted easily and inexpensively to do the same job with much less water.

Standard toilets are often built or adjusted to use more water per flush than is really needed to clear and cleanse the bowl. It is often possible to modify or readjust the toilet to use less water per flush. The simplest way to do this is by displacing some of the water in the tank. One of the most widely publicized ways to displace water is to place a brick in the toilet tank. This is not a good method to use. The brick can eventually crumble and allow particles to lodge in the seat of the valve that releases water into the toilet bowl. The result is a leaking toilet that wastes large amounts of water. Also, the brick may be dropped accidentally and break the toilet tank.

Another simple method of displacement is to place open containers, such as bottles or jars filled with water, upright in the tank. Unbreakable plastic is safer than glass but plastic must be weighted down--a few pebbles will work. The volume of water displaced by the container is saved at each flush.

Other displacement devices have been specially manufactured for the purpose. Toilet dams are flexible rectangular plates of plastic or metal with plastic edges, which can be fitted into the toilet tank. As their name implies, these dams hold back water--about

A Toilet Displacement Bag

1.65 gallons--and prevent it from leaving the tank. An advantage of dams is that they can be positioned in the tank to hold back varying amounts of water, allowing adjustment for optimum flush volume. Dams are usually available in pairs.

Another specially manufactured displacement device is a plastic bag, which can be filled with water, sealed, and hung in the toilet tank with a special clip. Bags are much less expensive than dams but the displacement volume of bags, about 0.68 gallons, is not as easy to adjust.

Some toilets need their full flush volume to dispose of solid wastes, and displacement devices cannot be used. However, a reduction in water use may still be possible. A number of retrofit devices enable selection among two or more flush volumes each time the fixture is used. Water is saved because a minimum flush volume can be selected for liquid wastes, and a larger volume of water can be used to dispose of solid wastes.

Showerheads may also be retrofitted to conserve water and energy by restricting the flow of water delivered to the showerhead. Flow restrictors may be inserted into the line between the shower arm and head or actually inserted in the showerhead. Both type of restrictors have a small orifice through which the water must pass, and both reduce flow to about 3 gpm.

It is sometimes possible to retrofit faucets in order to conserve water. Aerators can be added to existing faucets to reduce flow rate, provided that the faucets have threaded spouts. This can reduce maximum flows from 5 gpm to about 2.75 gpm.

The easiest and least expensive strategy available for reducing water use in the home is a change in water-use habits. This can result in further reductions in water use even in a household where fixtures have been retrofitted or replaced. By avoiding use of the toilet as an ashtray or wastebasket, turning the faucet off while shaving or brushing teeth, washing foods in a container of water rather than under a running faucet, and the like, interior residential water use can be reduced.

Water Conservation Reduces Sewage Flow.

Domestic Landscaping

The largest single use of urban water supplies in California is for irrigating the landscaped areas around homes and apartments. An estimated 30 percent of all urban water is used in this way. Statewide, 47 percent of an average household's water is used outdoors.

Tracing the history of landscapes in California helps us to understand why our outdoor water demands are so high, and suggests other alternatives. When the Spanish established a string of missions in California, they planted the first known ornamental gardens in the state. Their culture was from arid Spain, where water was a precious commodity. They came by way of Mexico, another very dry land. Consequently, the mission gardens were well suited to

California's Mediterranean climate. Plants were sheltered in courtyards where their water needs could be minimized. Outside the shelter of the mission walls, low water-using plants such as olive trees and palms were used.

The settlers from the eastern states and from England were accustomed to different weather patterns and different landscapes. These immigrants came from places which received summer rains that supported expansive lawns and towering deciduous trees with little or no supplemental water. Like the Spanish, they duplicated their familiar gardens here. Unfortunately, they could not duplicate the familiar weather patterns. They compensated by irrigating these landscapes all through the hot dry summer.

The same type of landscape remained popular as California's population grew. As long as abundant water supplies could be developed cheaply, these water-loving landscapes were inexpensive luxuries. Eventually, the landscapes so familiar to us today became almost required, as minimum lot sizes and setback requirements became law.

Variations in Landscape Water Use. A comparison between water use in areas with very little landscape irrigation and areas where there is much landscape irrigation can be striking. In San Francisco, population density is high, home landscapes are tiny or nonexistent, and the climate usually minimizes the need for supplemental irrigation. Urban per capita use in 1980 was 129 gallons per capita daily (gpcd). In Stockton, where there is more landscaping around homes and apartments, and the climate requires irrigation of any plants not adapted to the warm dry summers, water use in 1980 was 192 gpcd.

Within a single community, water use can fluctuate widely according to seasonal landscape irrigation needs. In 1980, January water use in Sacramento was 172 gpcd. In July of that year, water use soared to 472 gpcd. There is some increase in interior use during the summer, but most of this jump in water use is due to irrigation of landscapes.

Benefits of Lower Water Use. Today, Californians are rediscovering the benefits of low water-using gardens and are learning how to keep landscape water use down. New homeowners in increasing numbers are using plants well suited to the Mediterranean climate prevailing throughout much of California. Others are learning that even their traditional landscapes can be watered much more efficiently.

The benefits of a low water-using landscape are numerous and they may be substantial. The most direct benefit is a reduction in costs to the water supply agency and to material users.

Labor savings can be significant as well. Excessive water can promote excessive plant growth, and a low water-using garden requires less pruning. Mulch can help retain soil moisture and prevent the growth of weeds as well as reduce soil compaction. Sprinkler system timers reduce the routine attention paid to the landscape but must be properly set and monitored to reduce water consumption.

There are additional benefits to the landscape owner as well. Application of less water can reduce the likelihood of erosion on sloped areas. Essential nutrients are leached from the root zone more slowly when irrigation is reduced.

Methods for Reducing Landscape Water Use. Most of the established residential landscapes in California are of the traditional type, with large areas of lawn, some shrubs planted around the foundation of the home, and perhaps a few large trees. Although such landscapes were usually planted with little or no regard for water use, there are many actions which can be taken in these existing landscapes to reduce water use while still maintaining an attractive appearance. The result can be an average 20 percent reduction in landscape water use in urban and suburban homes with large yards.

The most direct way to reduce landscape water use is simply to apply less water. Many residential landscapes are irrigated at 20 to 40 percent above their evapotranspiration rates, and reducing the amount of applied water will have no negative effect. A precise way to control applied water in landscapes with fixed irrigation systems is to install timers, which turn the systems on at preset times and for preset durations. An added benefit is that timers may be set to activate during the early morning hours, when the wind is calm and the temperature is low. This keeps evaporation at a minimum. Care must be taken to adjust timer systems during the rainy season or unnecessary irrigation could result.

Evaporation may also be reduced by replacing sprinkler heads. Fittings that produce a fine spray at a high trajectory lose much water to evaporation. Heads that deliver large water droplets at a lower trajectory lose less water to evaporation.

Of course, no irrigation system is efficient when it is watering a sidewalk. Systems should be adjusted so that they deliver water to planted areas with as little water as possible falling on paved surfaces. Water application should be slow enough to avoid runoff.

Beyond the direct measures that reduce the amount of water applied are cultural practices that can increase the ability of a landscape to retain applied water. Most important is the use of soil amendments or mulches, which help to reduce soil compaction and keep moisture in the root zone where plants can use it. Surface mulches, such as wood chips, can also discourage the growth of weeds.

The application of all of these methods could result in a 20% reduction in water applied to an existing landscape. The actual water supply savings would depend upon how much reduction in evaporation and transpiration occurred and whether the excess applied water would have flowed to an unusable source such as the ocean.

<u>Low Water-Using Landscape Design</u>. A great many small improvements can often be made in traditional landscapes and irrigation techniques to reduce water use. However, much more substantial water savings can be attained by designing a landscape for low water use in the first place. Water use in a garden designed and maintained for low water use may be 40 to 90 percent lower than in a traditional landscape of the same size.

Those unfamiliar with low water-using landscapes may have formed stereotyped notions of their appearance. Low water-using landscapes can be designed to be colorful, with an abundance of showy flowering plants, or cool and shady, with large deciduous trees and shrubs. Cacti and succulents may also be used, but these are by no means the only choices.

The design of any garden, low water using or not, will follow the same steps. First, the future uses of the site are determined. An open recreation area may be desired, or a private area screened from other nearby homes. Whatever the intended use, a plan is drawn to accommodate it. Individual plant species are not designated, but categories of plants, such as screen plants or foundation plants, are specified.

At this point, water use should be considered. Within each category of plants are species that require large amounts of supplemental water and others that need very little irrigation in our Mediterranean climate. All the plant species to be used in a particular area of the landscape should have similar water requirements. If very low water use is a goal, the entire landscape may be created with plants that need little or no irrigation.

Careful preparation of the site is important. The site should be graded so that runoff to storm drains is minimized. Soil amendments, such as organic matter or compost, should be mixed in the soil, and wood chips or sawdust should be added to the top few inches of soil to reduce compaction and increase water-holding capacity.

Most low water-using landscapes will require some irrigation, and very efficient methods of applying this water have been developed. Shrubs and trees can be irrigated with drip/trickle systems, which apply water to a small area around the plant at a very slow rate. This system will lose almost no water to runoff, evaporation, or deep percolation if operated properly. Spray heads may be used for groundcovers, but they should be designed to minimize evaporation by emitting large drops at low trajectories. The irrigation system for each area of the landscape can be controlled separately by a timer, which irrigates on the appropriate schedule.

The use of porous paving materials such as decomposed granite or bricks, rather than nonporous concrete, can help keep irrigation requirements down. Rainfall or irrigation water which falls on porous paving can soak in and be used by plants, whereas water falling on nonporous surfaces often runs off to storm drains and is wasted.

Some Irrigation Water is Lost To Evaporation.

Lawns have a reputation for being high water users, but not all turfgrass varieties have the same water requirements. Tall fescue requires less water than Kentucky bluegrass, and improved bermuda requires less than tall fescue. Table 3 lists several turfgrass varieties in order of water needs.

Even within the areas of California with a climate that could be described as Mediterranean, there are certain clim-

Table 3. Water Requirements of Turfgrass Varieties

Variety	Water Requirements
Creeping Bentgrass	High
Dichondra	
St. Augustine	
Colonial Bentgrass	
Meadow Fescue	
Perennial Ryegrass	
Kentucky Bluegrass	
Red Fescue	
Tall Fescue	
Common Bermuda	
Zoysia	
Improved Bermuda	Low

Table 4. Plants Suitable for Inland Parts of the South Coastal Area

Latin Name	Common Name
Groundcovers	
Acacia redolens	
Artemisia caucasica	Silver spreader
Atriplex semibaccata	Australian salt bush
Eriogonum Fasciculatum	Common buck wheat
Gazania species	Gazania
Helianthemum species	Sunrose
Juniperus species	Juniper
Lippia concescens	Lippia
Myoporum parvifolium	
Osteospermum species	African daisy
Rosmarinus officinalis 'Prostratus'	Prostrate rosemary
Trifolium frageriferum O'Connors's	O'Connor's legume
Shrubs	
Eriophyllum confertiflorum	Gold yarrow
Leucophyllum frutescens	Texas ranger
Pennisetum setaceum	Fountain grass
Atriplex canescens	Four-wing saltbush
Baccharis pilularis consanguinea	Coyote brush
Callistemon citrinus	Lemon bottle brush
Dendromecon rigida	Bush poppy
Plumbago auriculata	Cape plumbago
Feijoa sellowiana	Pineapple guava
Nerium oleander	Oleander
Pittosporum tobira	Tobira
Romneya coulteri	Matilija poppy
Trees	
Acacia decurrens	Green wattle
Albizia julibrissin	Silk tree
Arbutus unedo	Strawberry tree
Brachychiton acerifolius	Flame tree
Ceratonia siliqua	Carob tree
Cercidium species	Palo verde
Dalea spinosa	Smoke tree
Eucalyptus polyanthemos	
Koelreuteria paniculata	Golden rain tree
Lagerstroemia indica	Crape myrtle
Prunus lyonii	Catalina cherry
Quercus suber	Cork oak

atic differences. Some regions have hotter summers, or have a greater likelihood of experiencing freezing temperatures in the winter. For this reason, a single list of low water-using plants cannot be compiled. Table 4 provides a list of plants suitable for inland parts of the south coast basin. A list for Sacramento or Oakland would have many of the same species but there would be some differences as well.

A more complete list of water-conserving plants may be found in DWR Bulletin 209, Plants for California Landscapes: A Catalog of Drought-Tolerant Plants, September 1979.

Converting Existing Landscapes. The substantial benefits of low water use landscapes, including savings in water, fertilizer, and labor, can make it attractive for homeowners to convert their traditional landscapes into low water use ones. The prospect of removing an entire landscape may well seem intimidating to most home gardeners. However, it is possible to convert a garden in stages, combining conversion efforts with routine maintenance. Many existing trees and shrubs can be retained, because established plants often have developed strong root systems and have adjusted to the microclimate in which they are planted. These plants may actually require much less applied water than they are receiving.

A good way to convert a traditional landscape is to modify it in stages, one section at a time. This way, the work and expense of establishing a low water-use garden may be spread over several years and the landscape as a whole never appears disrupted. Another advantage of converting a garden by sections, rather than piecemeal, is that new low water-using plants can be grouped together. This way, the irrigation of converted sections can be adjusted downward to suit the new plants. If a new low water-using plant were placed next to an existing plant with much higher water needs, the new plant might receive excess water. This could kill it, or condition it to need more water than it would otherwise require.

Figures 8, 9, 10, and 11 illustrate how a traditional garden can be converted by stages into a low water-using garden.

POOL VERSUS LAWN

The backyard swimming pool has become a very popular form of warm-weather recreation and a highly conspicuous use of water in California. However, a highly visible use of water is not necessarily a waste of water.

For example, a 25 by 40 foot established lawn requires about 27,000 gallons of irrigation water during a typical year. Many homeowners exceed this requirement by applying too much water, perhaps 40 percent too much.

By contrast, a 15 by 30 foot swimming pool, with a 5-foot-wide concrete border on four sides, will occupy the same area as the lawn just described. Such a pool would require about 17,000 gallons of water per year--for replacing evaporative losses and backflushing the filter. This does not count water lost to splashing or other losses. A pool with a cover uses even less water.

Thus, a swimming pool with patio can actually require much less water than a lawn of the same size.

Figures 8, 9 and 10 show how an existing traditional landscape with a high water-using lawn may be converted in stages into an attractive and functional low water-using landscape. Converting a landscape in stages allows the cost and effort to be spread over several years, and disruption of the entire area is avoided. Figure 8 depicts a traditional landscape with large areas of lawn, which requires large quantities of water.

In Figure 9, Stage 1, several large-canopy deciduous shade trees have been planted. Lawn along the street and driveway had been removed, soil amendments have been added to improve the water-holding ability of the soil, and low water-using groundcover has been planted.

In Figure 10, Stage 2, additional trees have been planted. Lawn in the side yard has been replaced with a low water-using groundcover. In the back yard, the lawn area has been reduced with beds of low water-using shrubs. At this point, landscape water use has been reduced significantly.

Even greater water savings can be achieved as shown in Figure 11. Additional lawn in the front and side yards has been replaced with groundcover. Beds in the back yard have been expanded, and the remaining turf area has been planted with a low water-using lawn species. Porous paving--brick entry and decomposed granite walkway--has replaced the concrete. A wooden deck has replaced some lawn in the back yard. Once established, this landscape will use far less water than the landscape shown in Figure 8.

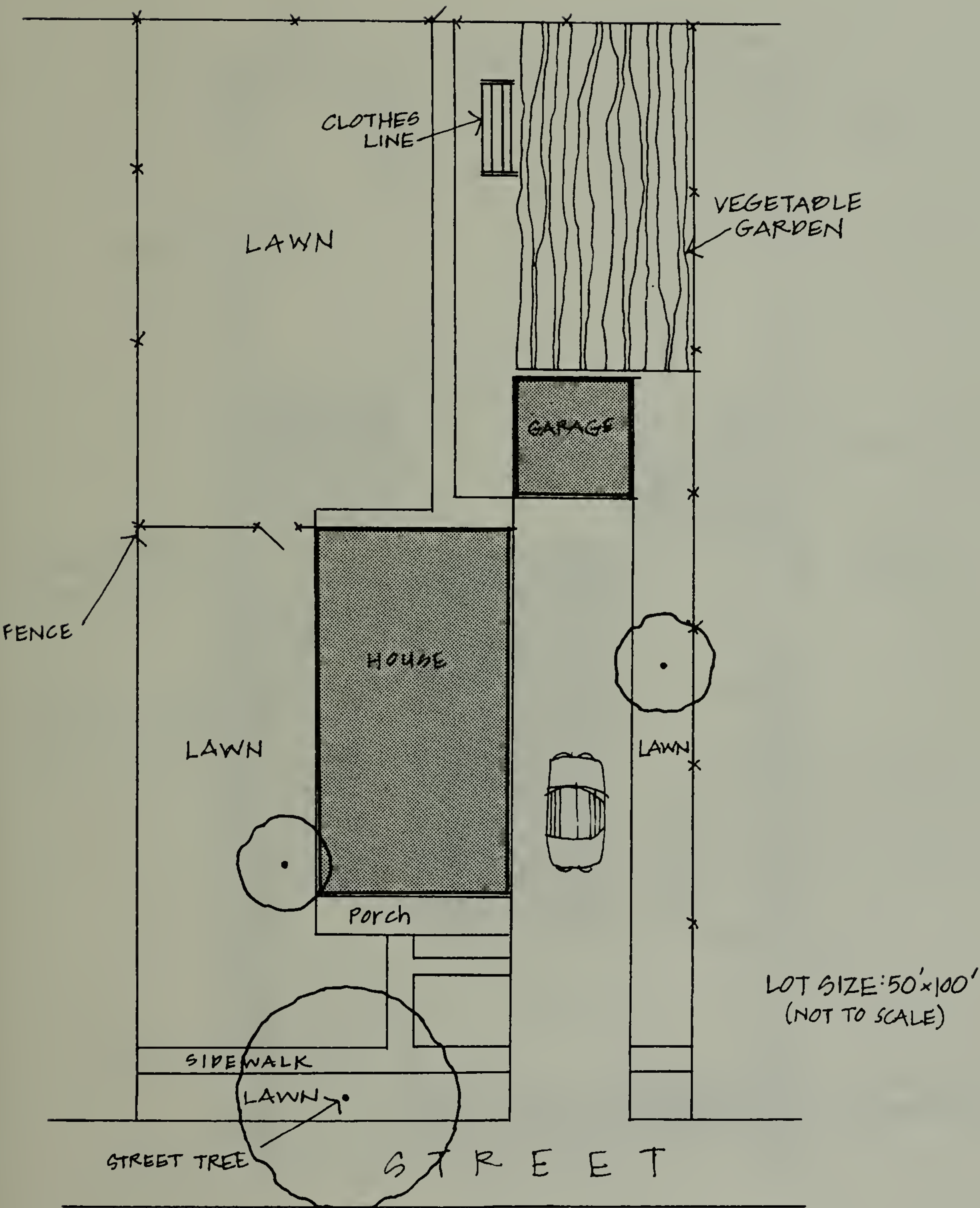


Figure 8. A Traditional Landscape

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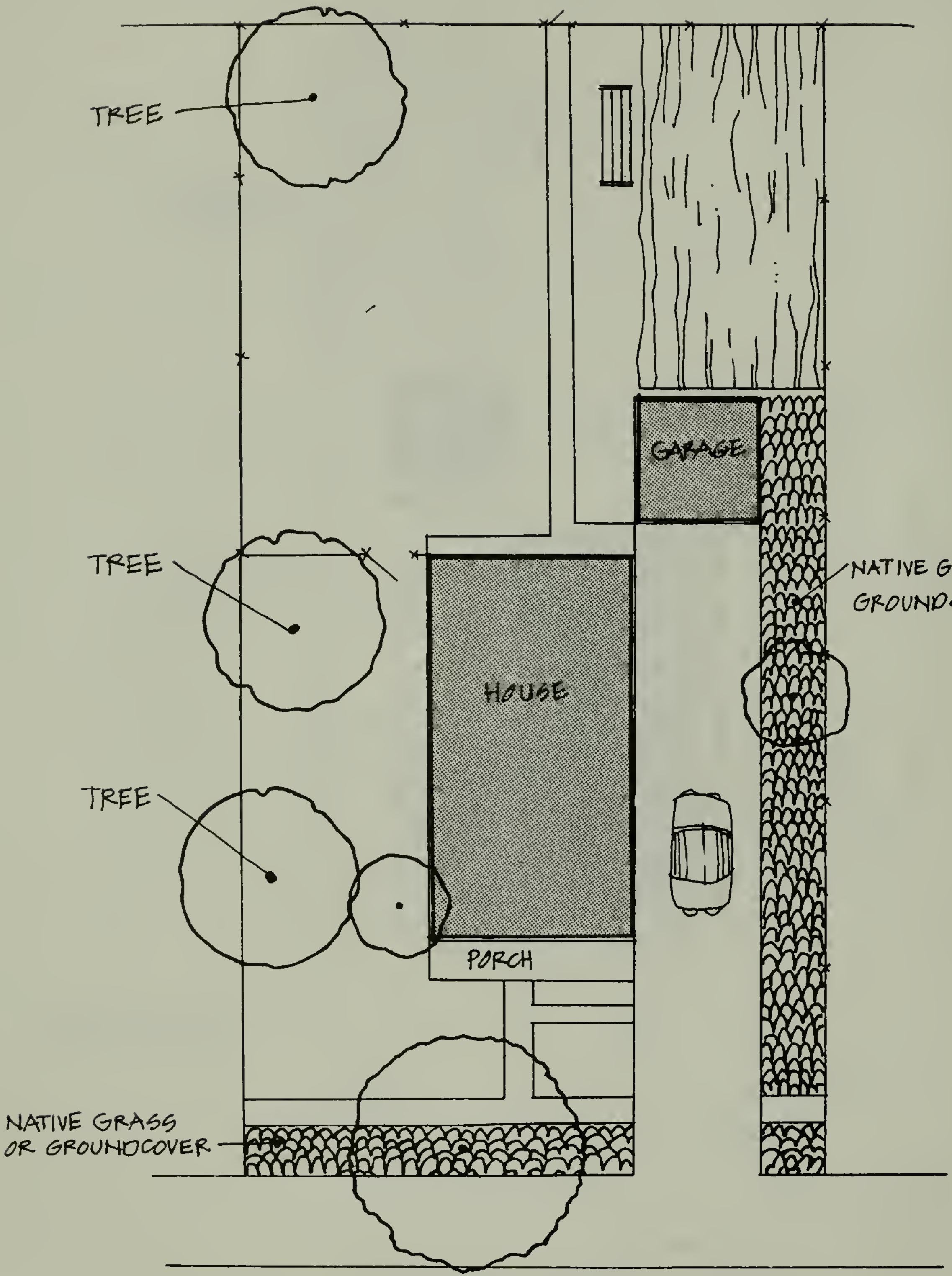


Figure 9. Landscape Conversion - Stage 1

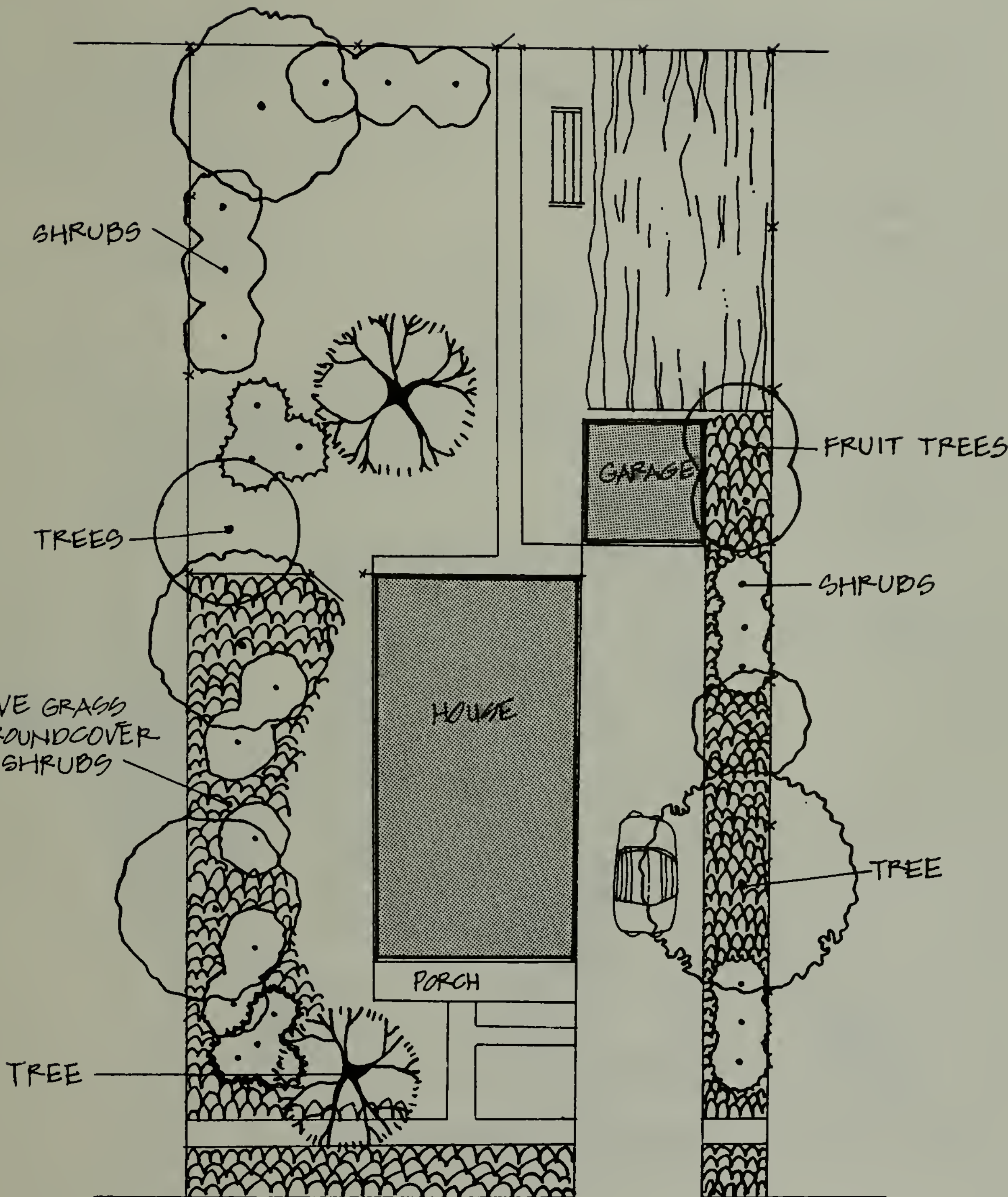


Figure 10. Landscape Conversion - Stage 2

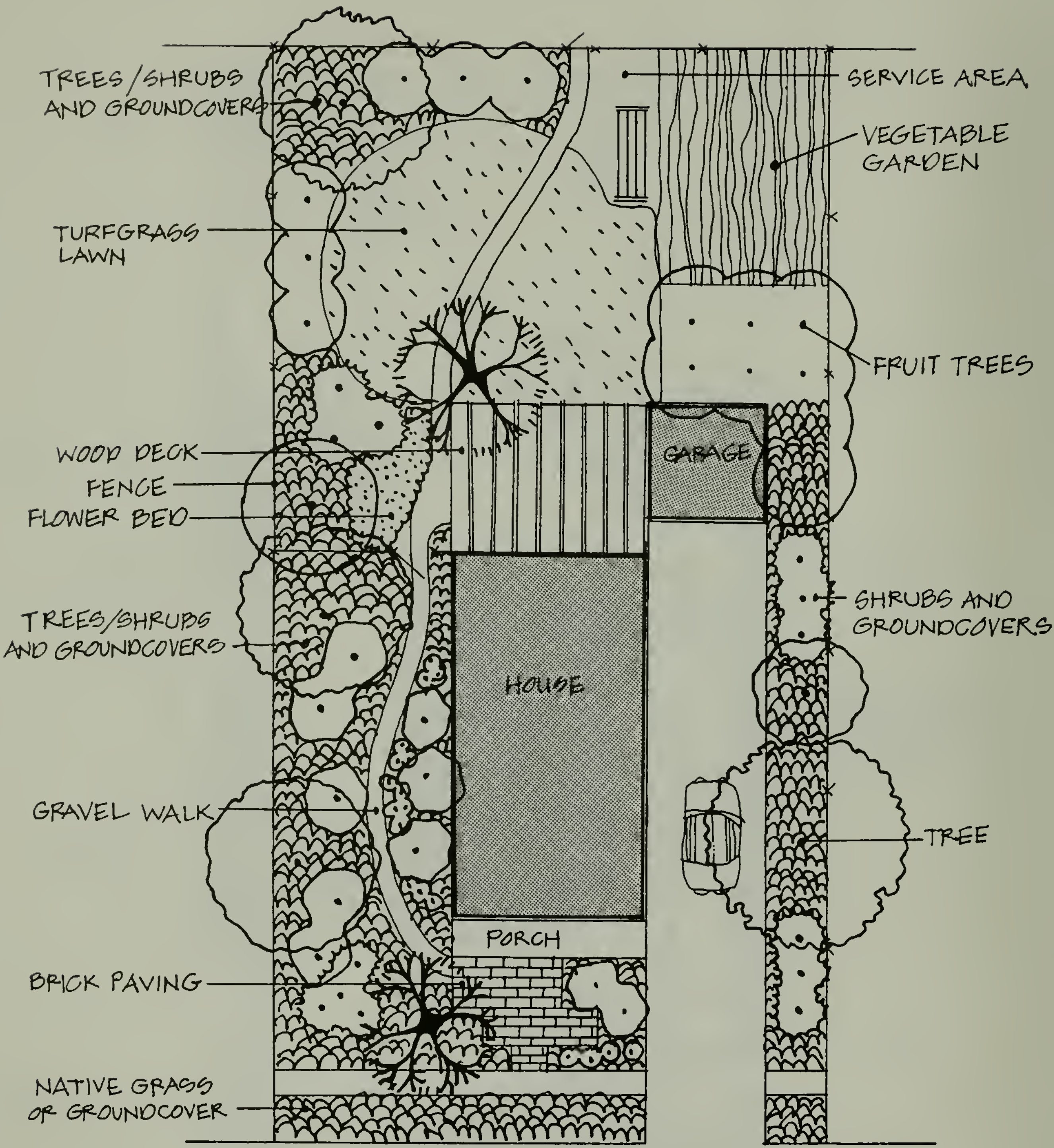


Figure 11. A Low Water-Using Landscape

PLANT SELECTION: NATIVE VERSUS MEDITERRANEAN

A key principle of low water-using landscape design in California is the selection of plants that have become well adapted to the mild, wet winters and the hot, dry summers experienced in most the State. Meteorologists refer to this as a Mediterranean type climate. Almost any plant adapted to such a climate will be suitable for a low water-use garden here, whether the plant is native to California, the lands bordering the Mediterranean Sea, or any other part of the world with a similar climate.

Many ornamental varieties used today in low water-use landscapes are native to Australia or East Africa. Figure 12 shows locations throughout the world that have provided plants suitable for California's climate.

Being a California native is no guarantee of a plant's suitability for the low water-using garden. Some of our native species are adapted to moist riparian areas or to the rain-drenched forests of the North Coast. Such plants, however, will not do well in a low water-use garden in the Central Valley or along the South Coast.

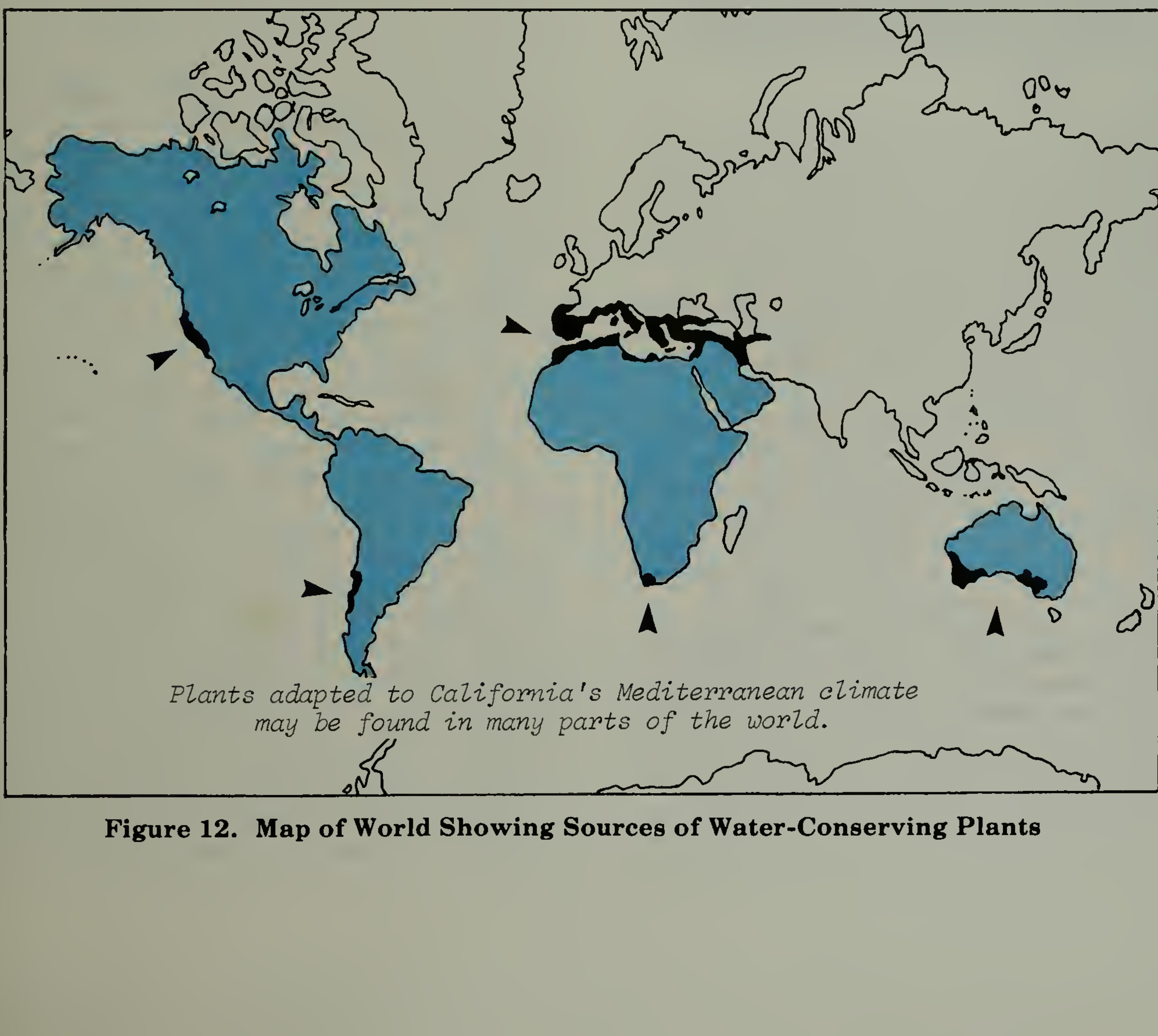


Figure 12. Map of World Showing Sources of Water-Conserving Plants

Commercial and Governmental Water Conservation

Commercial and governmental water use is similar in many respects to residential water use, and many of the same conservation measures used in homes are applicable to commercial and governmental establishments.

Interior Use

The largest interior use in the commercial and governmental sectors, as in the residential sector, is for toilet flushing. Water closets and urinals in public and commercial restrooms, like residential toilets, may be retrofitted to reduce flush volume. The flushometer valve commonly used in public restrooms is easily retrofitted by placing a disk in the valve, which makes it close sooner and pass less water per flush. However, care must be taken that flushing action remains strong enough to cleanse the bowl so that public health is not jeopardized.

Although the technology and methods for commercial and governmental water conservation are readily available, the motivation to conserve may be low. The cost of water is a very small part of operating expenses for most businesses, and water conservation may receive little attention. Water agencies can promote conservation in the commercial sector by suggesting cost-effective retrofit measures, by pointing out the indirect savings that are possible (such as energy savings when hotel showerheads are replaced with low-flow heads) and by suggesting that comparisons of water and energy use among different models be made when equipment such as clothes washers and dishwashers are replaced. Water agencies may also require reasonable conservation measures as a condition of new service. Many conservation measures, such as water-efficient fixtures and low water-use landscaping, are no more expensive than traditional alternatives if installed at the time of construction.

Local government agencies, including those with large water needs such as parks departments and school districts, often have no incentives to conserve because they receive unmetered water service. By metering government water service, charging agencies for water delivered, and establishing local policies concerning governmental water conservation, local water departments can promote more efficient use of water by government agencies.

Landscape Water Use

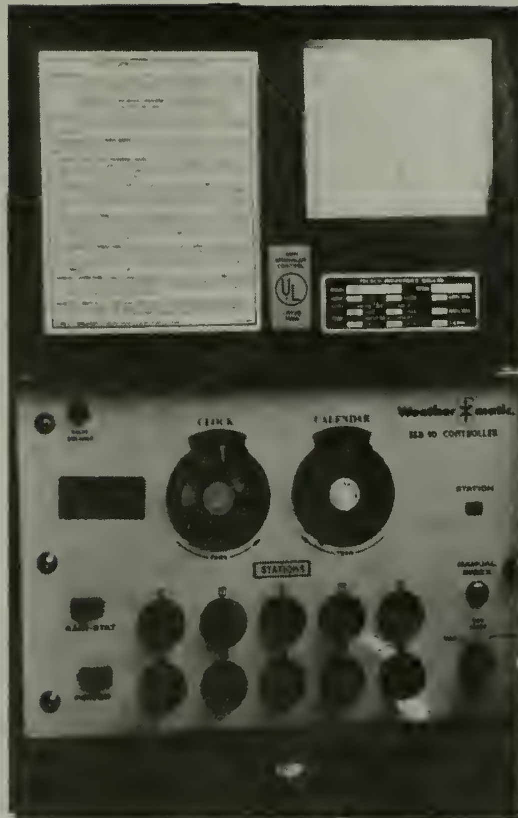
Commercial landscapes are generally quite similar to residential landscapes, and the same water conservation measures are applicable. There are incentives for businesses to choose water-conserving landscapes because the additional water and labor requirements to maintain traditional landscapes are added costs of doing business. On the other hand, the cost of landscape irrigation water is generally a very small part of total expenses, and the possibility of reducing landscape maintenance costs is not always evident to business managers. Finally, business people may perceive a need to model their new landscapes after existing commercial landscapes, which are usually traditional and use substantial quantities of water.

There are examples in increasing numbers of successful landscapes with very low water needs, however. Major commercial landscape maintenance firms are achieving water savings of 50 percent or more through new techniques. One fast-food landscape architect now designs most outlets with low water-using, low-maintenance landscapes. These low water-use landscapes, once established, require only 40 to 60 percent of the water required by traditional designs, and the traditional landscapes are more expensive to maintain. The savings is realized because there is no lawn to be mowed weekly, weed growth is discouraged by mulch and careful water application, fertilizer needs are lower, and pruning is required less frequently.

Some landscapes will still contain areas of lawn, but water use can be reduced nevertheless. For instance, developers of garden apartments and condominiums have been able to balance residents' desires for a traditional landscape and lawn areas for recreation with their own desire to keep water and maintenance costs down. This can be done by both reducing the size of lawn areas and increasing the visual impact of the lawn through careful design. Shrubs, trees, and groundcovers used elsewhere in the landscape are low water using and existing trees have been retained where possible. With this approach, several apartment complexes and condominiums in Novato, Marin County have reduced water use 40 percent compared to similar developments with traditional landscapes.

Some commercial landscapes, such as golf courses, require large lawn areas. However, turfgrass varieties with reduced water needs are now available, and these varieties can be used in new golf courses. Introducing more careful water management techniques can reduce water applications on existing courses as well.

Care of turfgrass has become very scientific, and the grass is treated much like an agricultural crop. Evapotranspiration is considered, and water is applied strictly according to plant needs. The array of electronic equipment available to maintenance personnel is impressive. Sprinkler heads are specially designed to minimize evaporation. On golf courses, the greens, fairways, and rough areas are irrigated on different schedules according to water needs. Irrigation systems are turned on automatically by a system that measures soil moisture using a tensiometer and applies water only when it is needed. To minimize evaporation, an anemometer in the system monitors wind speed and postpones irrigation until



A Sophisticated Irrigation Timer

calm periods.

These efforts may sound extreme, but the financial benefit to a business maintaining a large area of turfgrass can be very large. The Cathedral City Country Club in Riverside County has begun to adopt the practices described above. Water use to irrigate the golf course has been reduced 70 percent. Energy bills to pump the water from wells have been reduced $32,000 per year. With less applied water, turf disease is minimized and fungicide use can be reduced. Fertilizer needs are lower because there is less deep percolation of water.

The water conservation measures described for commercial landscapes will also apply to public landscapes. These include gardens around public buildings, parks, school yards, roadway medians, and freeway rights-of-way.

In addition to the direct benefits of landscape conservation programs, public agencies can use their landscapes as demonstration sites to provide examples of water-conserving gardens and to promote landscape water conservation by homeowners and businesses. Water agency offices are obvious sites for demonstration gardens, but there may be better choices. The landscaped areas around new schools, other than playing fields, are perfect for demonstration gardens. They are located in neighborhoods where many new landscapes are being established and the gardens can serve as outdoor classrooms.

Median strips are also high-visibility areas where low water use plantings can have a strong impact on community residents. Since maintenance costs are often very high for medians, low-maintenance water-conserving landscaping is an especially attractive alternative. Some communities have also observed that the life of pavement is extended when irrigation water running off to it is curtailed.

Many local government agencies receive unmetered water service from municipal water supplies. This provides little incentive for conservation. Even if funds are only transferred from one city department to another, public agencies should be notified of their water use and billed accordingly. This will give the agencies an awareness of their consumption and some incentive to use water wisely.

Industrial Water Conservation

Industrial water use in California claims the second largest share of urban water supplies, accounting for about 15 percent of the total urban applied water. Although the number of industrial plants has increased by about 4,000 since 1970, to some 36,000 today, industrial applied water has actually decreased. Industrial water use in 1970 was about 950,000 acre-feet, but 1979 applied water amounted to only 918,000 acre-feet.

The decrease in water use by industry can be attributed in large part to conservation and water recycling efforts. Many of these efforts were taken by manufacturers in response to the Federal Water Pollution Control Act of 1972, which required that waste dischargers pay their proportionate costs of regional waste treatment. Many industries reduced discharges by reusing water supplies and modifying processes to use less.

Industries use water in a wide variety of ways. Some of these include the use of water in cooling towers and the use of water for floor washing and other cleaning. Water-conserving techniques developed in one industry can often be adopted by another industry. Water is routinely recycled in cooling towers, and methods of retaining as much of this water as possible are being adopted more frequently. Sometimes water use can be reduced through a better understanding of where the water is being used. Installing submeters to trace water use within a plant is often helpful in reducing water use.

Many companies have been able to achieve remarkable increases in water use efficiency. A Southern California brewery has been able to reduce the water used per barrel of beer produced by 65 percent. This has allowed an increase in production with a net decrease in water use. Some oil refineries have reduced intake of fresh water 15 to 20 percent.

By reusing water extensively, some industrial firms have cut fresh water intake by as much as 95 percent.

DWR expects industrial conservation efforts to increase as older equipment is replaced, as efforts to reduce sewer, water, and energy bills continue, and as additional attention is paid to the possibilities for water reuse.

Each city and town in California has a unique set of conditions that govern the rate of urban water use, the potential for water conservation, and the benefits to be gained from water conservation programs. In places where sewage effluent is discharged to the sea or to a river where there is no downstream use, water conservation is particularly beneficial because the water saved would otherwise be lost. Reductions in evaporation and transpiration from landscapes are very beneficial because this water cannot be reused once it is lost to the atmosphere.

Even when conservation programs do not produce these water supply savings, there are still important benefits. The water purveyor may experience benefits such as reduced operating costs or delays in the need for additional supplies. Consumers may experience benefits such as reduced water and energy bills.

The need and justification for conservation programs should be clearly defined so the most appropriate measures can be selected for each situation and objective. Then, the appropriate community agency or group can implement each measure selected. Most commonly, it is the water agency or water department that undertakes conservation programs. The goal may be to reduce peak water demands, or to slow the increase in water demand over the short or long term.

Other entities, including cities and counties, school districts, sewer districts, and energy utilities, may also undertake water conservation programs. These efforts may be made independently or in cooperation with water suppliers. The following sections describe various conservation programs.

Leak Detection

Most water delivery systems have some loss of water due to leakage. To determine the statewide potential for leak detection, the Department commissioned a study, Municipal Leak Detection Program Loss Reduction: Research and Analysis, August 1982.

This study reports on a survey of the leak-detecton efforts of California municipal water systems, leak-detection equipment and procedures, and the results of three leak-detection demonstration efforts conducted in California communities.

The survey found that approximately four percent of California's urban water supplies are lost to underground leaks. The study found that almost 75% of this leakage could be economically detected and recovered using existing technology.

Water Audits

To determine whether a leak detection and repair program could be cost effective in a particular district, a utility can conduct a water audit. This is a

Leaks Can Cause Serious Water Losses.

process of accounting for an agency's water from the source of supply, through the distribution system, to delivery. The difference between the measured amount of water entering the system and the measured amount delivered to customers is called "unaccounted-for" water. This unaccounted-for water can be divided into two categories: authorized uses and unauthorized losses. Authorized uses include such uses as fire fighting, main and sewer flushing, street cleaning, and public uses such as watering for parks, schools, and cemeteries. Unauthorized losses include components such as leakage, metering errors, theft, and inaccurate system controls.

Once the amount of recoverable leakage is estimated, the economic benefits to the utility can be calculated. Leakage is water the utility has already paid to develop, treat and distribute. When a utility recovers leakage it will usually cut back on the water obtained from its most expensive source. Therefore, the benefits are usually equal to the unit costs of water from the most expensive source plus the variable operation and maintenance costs.

Leak Detection Equipment in Use

The costs for detecting the leakage can be easily calculated using data available on frequency of leaks, equipment costs, and the like. If the economic benefits exceed the costs, a water utility should carry out a leak detection program.

Finding Leaks

Many leaks are easy to find. They may be revealed as damp areas or puddles over water mains, or in visible damage such as a collapsed section of the street. Water agencies quickly become aware of leaks such as these and repair them promptly. Many other leaks, however, do not surface. Instead, they take the path of least resistance and soak into the ground, enter sewer pipes or storm drains, or flow into streams.

The most common method of detecting leaks in underground systems is by listening for them. Water leaving a pipe or main makes a hissing sound which can be detected through the use of specialized listening equipment. These instruments range from simple devices similar to stethoscopes to sophisticated computer-assisted electronically amplified and filtered acoustical monitors.

Commonly, the equipment used by a water agency will consist of an acoustical pickup and an electronic amplifier. Most leaks from a fraction of a gallon per minute on up can be found with this type of equipment, which ranges in cost from under $500 to about $2,600.

Computer assisted equipment can provide superior accuracy in pinpointing the location of leaks, saving excavation time and labor costs. Prices for such equipment range from $18,000 to $45,000.

Water utilities base their leak-detection effort on the severity of the loss problem and the availability of staff and financial resources. Larger systems may opt for an on-going program with a specialized crew providing systematic coverage of each main on a set schedule. In a smaller system where a full-time operation is not justifiable, management might choose a periodic program of full coverage, using personnel borrowed from other duties temporarily. Other small utilities employ specialized consultants; this offers the advantage of state-of-the-art technology and expertise without a financial commitment to equipment purchase or staff training.

Some agencies prefer a program concentrating on known problem areas of the system. These areas are identified by conducting a water audit that isolates zones with excessive flow or a history of observed leaks. Potential problem areas can also be identified by recording night flows within a section of the system. This is usually done by placing a recording meter on a main and selectively opening valves to enlarge the area being monitored by the meter. When the opening of a valve causes a marked increase in flow, it is a sign for further investigation. The flow increase might be a leak, or a normal nighttime major water use such as a laundry or other industrial application. This method is normally used to locate the largest leaks. Figure 13 shows representative water main flow over 24 hours.

Meter Maintenance Program

Many wholesale and retail water utilities have meter maintenance and calibration programs for source meters and customers' meters. Broken, stopped and inaccurate meters may be the cause of a high percentage of unaccounted-for water. Most customers' meters under-register over time and result in substantial losses of revenue. Smaller water utilities often hire consultants to design the program and a service company to implement the program.

Meter maintenance programs are almost always cost effective. The replacement schedule for meters depends on the size,

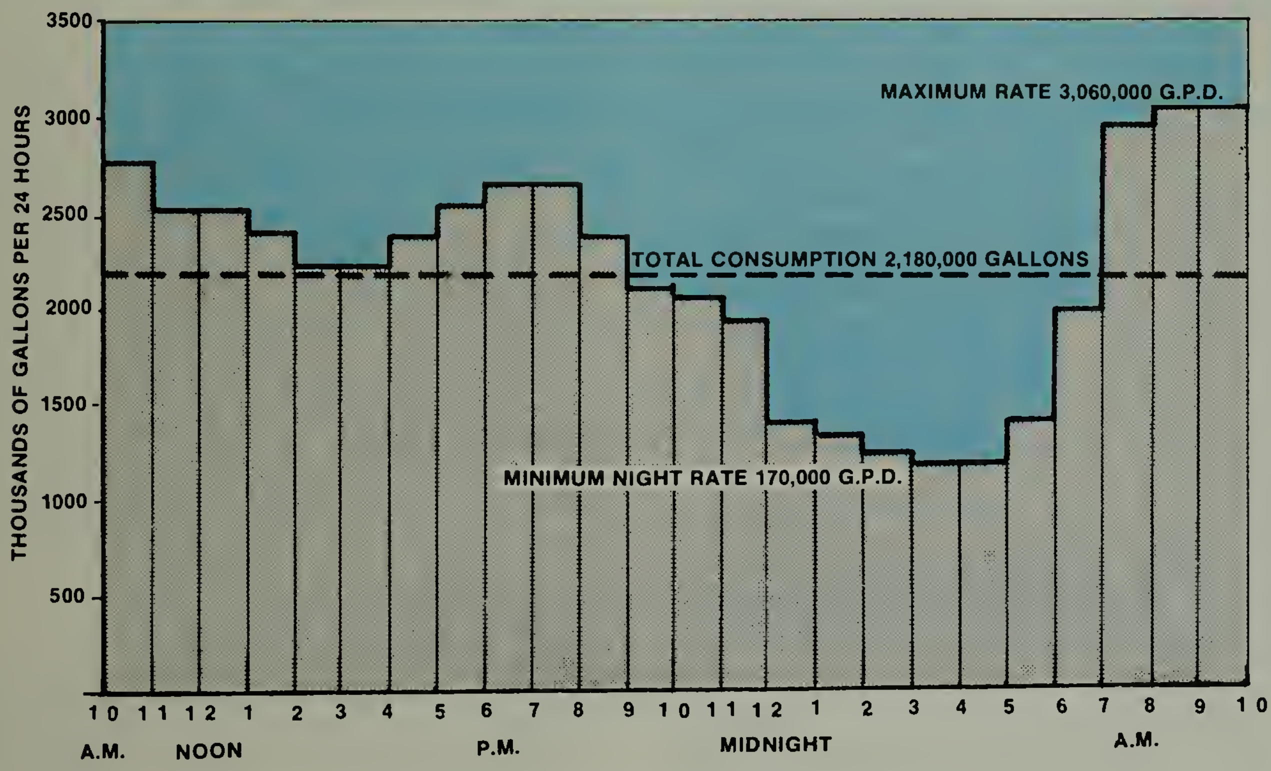


Figure 13. Representative Urban Water Use Over 24 Hours

type and age of the meters, water pressure, water quality, geographical location of the service area and cost of the water. The large meters should be checked for accuracy and replaced or repaired more often than domestic meters because of the larger amount of water measured and greater potential for revenue loss due to underreading.

Corrosion Control Program

The purpose of a corrosion control program is to reduce deterioration of pipelines and storage tanks in order to conserve water, lower maintenance costs, and increase the service life of facilities. Many measures can be included in a corrosion control program, such as routine inspection of facilities, treating the water, installing noncorrosive pipelines, and cathodic protection.

Valve Exercising Program

An on-going valve exercising program is essential for a utility to have an efficient distribution system. Utilities that do not have such a program may find that valves are open instead of being closed, valves are broken, valves thought to be left handed are right handed, some valves are not on the distribution maps or are in the wrong location, the number of turns to operate valves is unknown, or that valves are leaking. All of this can result in water loss or inefficient repair of leaks. A valve exercising program consists of exercising each valve on a regular basis to check for proper functioning, location, and potential problems. A valve log should be used to record all important information about the valve including the sequence for opening or closing each valve.

Benefits

The Department analyzed the cost effectiveness of leak detection in its report, An Examination of the Benefits of Leak Detection, May 1983. This analysis included variable rates of interest, variable costs of water, fixed costs of leak detection and repair of leaks, variable amounts of initial leakage and variable lifetimes of leaks. The finding was that leak detection programs are a cost effective way for almost all water utilities to cut costs and save water.

Benefits associated with leak detection accrue from several sources. Agency expenses for the purchase and treatment of water are reduced. Energy requirements for pumping water will also be lower. Expansion of facilities for water treatment and storage of finished water will not be needed as soon. Unlike many other conservation programs, leak detection involves no reduction in revenue. A leak detection program offers an opportunity to demonstrate to the public that the agency is committed to reducing expenses and minimizing losses.

Another important benefit is the prevention of property damage. Large underground leaks that go undetected for a long time can eventually cause the collapse of nearby roads and buildings. A leak detection program could prevent some leaks that later result in serious main breaks.

Costs

The Department's leak detection demonstration projects provided data on the costs for leak detection. The average cost for a full-time two-person survey crew, sonic leak detection equipment, and truck is about $225 per day when assigned to leak detection full-time. A crew would be able to survey an average of 2 miles of main per day. The cost of repairing leaks varies according to the type and location of the leak. Small leaks such as those at meter boxes may cost as little as $15 each to repair. Larger leaks requiring excavation may cost over $500 each to repair.

Local Efforts

There are at least a dozen water utilities in California with on-going leak-detection programs. Many of the larger utilities have extensive programs. The Los Angeles Department of Water and

Power began a program in 1976 using four two-person crews. These crews survey the agency's 7,000 miles of distribution pipe and 680,000 services, repairing minor leaks and pinpointing serious leaks for repair crews. The leak-detection crews also respond to customer problems.

Smaller agencies have found that leak-detection programs can be cost effective for them, too. The City of Santa Cruz established a leak-detection program in 1981. A single one-person crew surveys the system's 300 miles of pipeline and 20,000 services full time. In the first year, 50 percent of the system was surveyed, and 90 leaks with a total flow of 260 gallons per minute were detected and repaired. The city estimates annual cost savings for this flow to be $96,000. In addition to the water savings, the city has found that by being able to pinpoint leaks, they are able to expose the leaks with a single excavation 85 percent of the time. This can save one-half of a crew day plus additional pavement replacement.

DWR Program

DWR will distribute $1.3 million in grant funds to about 50 medium sized water agencies for conducting water audits and initiating leak detection programs. Funds are from the Clean Water and Water Conservation Bond Act of 1978. Selection of utilities will be based on the benefit cost ratios estimated in their applications. Participating utilities will record how much leakage is actually recovered as a result of the program. If actual benefits exceed actual costs, utilities will be expected to continue leak detection using their own funds.

Water Rates

As the price of almost anything rises, people will buy less of it. For some goods, such as bread or milk, the price charged has little effect on the amount purchased; however, for other goods, such as apples or oranges, the amount purchased will fall as the price increases. The effect of price on consumption is measured by this price elasticity of demand. The price elasticity of demand for a good is the percentage fall in consumption that will result from a one percent increase in price. For example, if a one percent increase in the price of a particular good will result in a half percent fall in the amount purchased, the price elasticity of demand is 0.5.

Studies conducted in California and Arizona cities with suburban family water costs in the range of $280/acre-foot to $442/acre-foot (in constant 1982 dollars) suggest that the price elasticity of demand for piped water is about 0.3 (Young 1973, Agthe and Billings 1980, Conley 1967). This means that if the price of water increases from these price levels by ten percent, use will fall by about 3 percent. The reduction in demand will likely be higher in areas which already have high water prices. It appears that people reduce their use the most in the summer when large amounts of water are used for watering landscapes.

Until recent years, when more communities have adopted conservation-oriented rate structures, many California consumers had little incentive to reduce water use. When customers with some types of rate structures reduced water use, they did not receive a like reduction in their bills. Many communities still use the older types of rate structure which do not encourage conservation. Below are descriptions of some of the more common rate structures currently in use:

Flat Rate. A flat-rate structure is typically used in an unmetered area. The agency usually charges each customer a set fee, which is determined in advance. Usually, all customers within a certain use type (such as single-family houses) are charged the same dollar amount without regard to the actual amount of use. Since the customer's bill is unaffected by the amount of consumption, the rate offers no incentive to use water efficiently. The majority of flat-rate structures in California occur in the Sacramento-San Joaquin Valley.

Uniform Rate. Under uniform rates the agency charges by the units of water used. Each unit is sold at the same price. A customer using twice as much water as another would have a bill twice as high. A reduction in water use will be matched by a like reduction in charges to the customer.

Declining Block Rate. Under this rate structure, the agency charges for each unit of water used. Unlike the uniform rate, unit prices go down as use goes up, thus providing a quantity discount. Customers who reduce water use, receive a less than comparable reduction in their bills. This discourages conservation. Many agencies are moving away from this rate structure.

Increasing Block Rate. Under this rate structure, the agency also charges for each unit of water used. It is the inverse of the declining block rate structure. As water use increases, the unit price also increase. Customers who reduce their use receive larger reduction in their bills. This encourages conservation. Although this rate structure was relatively unheard of a decade ago, it has been adopted in a number of water agencies.

Seasonal Rate. Under a seasonal rate structure, the agency charges a higher unit price for water sold in the summer than in the winter. Since customers have more ability to reduce demand in the summer by cutting back on landscape irrigation, this rate structure can significantly increase conservation. Although the use of this type of structure is not widespread, it is drawing more attention and has been adopted by some agencies.

In addition to the unit charges, some agencies' rate structures provide for base charges or service charges. These charges discourage conservation by lowering the unit price charged for the water. Likewise, when property taxes are included in the agency revenues permitting lower per unit rates, conservation is discouraged.

The use of innovative rate structures has increased in the last several years. Although the use of these rate structures is still not widespread, they are under consideration in many communities concerned about encouraging conservation.

Following are a few examples of innovative rate structures adopted in the last several years. This list is not meant to be all inclusive.

- Palo Alto, California began a gradual switch to an increasing block rate structure in July, 1976. The quantity rate in the last block is 98 percent higher than the first block rate. Palo Alto also charges users living at higher elevations more for their water through separate rates for six different pressure zones. They report no problems with customer acceptance.

- Beverly Hills, California has had an increasing block rate structure for a number of years and reports no problems with customer acceptance. The city also has a unique system of surcharges and credits that encourages decreased water use.

- Carson City, Nevada has had increasing block rates for almost ten years. It has two rates with rather steep blocks. One is for residential accounts, and one for commercial customers. The utility's customers don't like their high water bills, but there has been no significant protest against the rate structure.

- Dallas, Texas introduced a special surcharge on summer water use in February 1977. All residential water over 20,000 gallons per month for the June through September period was billed at a rate about 17 cents more per 1,000 gallons than the regular rate. According to a Water Department official, this was done to "recover some of the costs of peaking," as well as to promote water conservation. There was no significant public reaction against the new water rate schedules.

Since 1977, Dallas has increased the "summer differential" to 22¢/1,000 gallons, and applied it to all residential use over 15,000 gallons per month. They have a summer surcharge for commercial and industrial water, although it is only 6 cents per 1,000 gallons. They also charge for sewer service based on monthly water consumption.

The Washington Suburban Sanitary Commission, located north of Washington D.C., serves about 230,000 accounts. In the mid-1970s, the city's sewer system had reached capacity. To help meet this problem, they appointed a broad-based Citizens Advisory Group, which held public hearings and then recommended water rate reforms to reduce water and sewer use. In January, 1978, following the recommendations of the Advisory Group, the Commission introduced an increasing block rate structure.

Today, this unique increasing block rate structure contains 100 different blocks and applies to all water users, except for multi-family residential users. (Those accounts have their own increasing block rate structure, where the bill is based on the number of apartment units as well as monthly water use.) Sewer bills are also based on water use, which further encourages water conservation. The Commission also charges a rather high "system capacity charge" on new hook-ups, based on the size of the connection. Attractive quarterly brochures enclosed with the water bills give the reasons for the "conservation-oriented rate schedule", and clearly explain how water and sewer bills are computed. Customers know that if they use more water, they will pay for it at a higher rate.

These innovative water rates have helped reduce average household water consumption in the service area by 18 percent, from 300 gallons per day before the new rates were introduced, to 245 gpd. A Commission official states that there have been complaints about the new rates from large commercial and industrial users, and from families with large lots. However, there is a widespread community acceptance of the rates, for people realize that they encourage water conservation, and were recommended by a representative group of citizens. The same official concludes "You can make it work, even if you do get some flack at first."

The introduction of new water rates can sometimes be unpopular. In June 1976, a novel rate schedule was introduced in Tucson, Arizona. In the face of rising water costs and a looming shortage, the City Water Department introduced increasing block rates, an extensive system development charge for new connections, and a system of eight lift zones, where people living at higher elevations would pay more for their water.

This was too much for the people of Tucson, especially at the start of the peak summer watering season. Some families living on large lots in the higher elevations saw their water bills suddenly skyrocket to over $800 a month. A recall campaign was started, led by developers opposed to the high connection fees, and people living in the hills, opposed to the lift zones. Other issues besides the water pricing charges were involved in the recall drive, which succeeded in defeating each council member who had voted for the new water rates.

In response to the public outcry, the City Council and Water Department took a number of actions in the year following the water rate changes:

1. A Citizen's Advisory Water Committee was appointed to recommend revisions to the new water rates, and ways to deal with the city's water problems. They issued their report in February 1977.

2. A series of "Water Workshops" were organized to educate the public on the region's water problems.

3. The unpopular lift charges and system development charges were dropped.

4. A "Beat-the-Peak" water conservation program was started in the summer of 1977.

5. New water rates were adopted in April 1977. These rates were even higher than the old rates, although the monthly service charges were lower. There was a constant rate for winter water and an increasing block rate structure for summer residential water. Large multifamily and commercial customers paid a surcharge based on the extent to which their summer use exceeded their winter use. These new, progressive water rates were accepted by the citizens.

Since 1977 a better informed and more involved public has also accepted further water price increases and additional water rate reforms, such as an increasing block rate structure for winter residential water.

Several studies have concluded that water rate reform in Tucson helped to dramatically lower that city's water use. Before July 1976, year-round per capita water use averaged about 185 gal/day. By fiscal year 1978/1979, average use was down to 140 gal/day, a 24 percent decrease. Summer use has declined even more than winter use.

Establishing New Water Rates

Local elected officials and water district managers desiring to promote water conservation through innovative water rates can learn from the experiences of the above cities. Water rate reform can be implemented elsewhere in a step-by-step manner.

First, a Citizens Water Advisory Committee should be appointed. This will help ensure adequate community input from the very beginning. It should consist of representatives from the water agency and other appropriate public offices. Other members could include private citizens. Community organizations such as the Chamber of Commerce, labor organizations, the League of Women Voters, and various other civic and political organizations can be included. The Advisory Committee would deal with measures to promote water conservation, including water rate reform. The Advisory Committee should have appropriate staff and budget.

The Committee could first study local water problems, the need for conservation, and how water rate reform has been done elsewhere. Public hearings on water rates should be held to take testimony from expert witnesses and the general public. Finally, it would make recommendations to the appropriate governing body such as the City Council or water district board.

The recommendations of the Advisory Committee that are approved by the city council or water district board should be implemented slowly. If new rates are recommended, the rates and the reasons for them should be discussed in newspaper articles, on local television and radio talk shows, and before local civic, political and environmental organizations. The water department's customers should be informed of the new water rates through bill stuffers several months before the new rates become effective. The actual implementation of the new rates is perhaps best begun during the winter, when they will have the least impact on water bills.

Finally, rate changes should be made incrementally. For instance, even if the decision were made to switch to increasing block rates, seasonal surcharges, lift zones, and special system development charges, it would be wise not to do so all at once.

Metering

In order to charge for water according to the amount delivered, customers' water use must of course be metered. If customers' water bills are the same, regardless of how much water they use, they have little incentive to use water efficiently. There is no doubt that charges based on quantity consumed reduce water use. A 1968 comparison of water use in 12 San Joaquin Valley cities (six metered, six unmetered) showed that per capita water use was 42 percent lower in the metered cities. A study of 21 cities throughout the nation for the 1900-1935 period showed a long-term average drop in per-capita water use of 35 percent when the cities went from being primarily flat rate to rate structures based on the quantity of water consumed. In the 1960s, Boulder, Colorado experienced a 36 percent decrease in per-capita water demand after its residential accounts were metered. Finally, a 1980 DWR study compared 1979 single-family residential water consumption in unmetered Chico with metered Stockton. In Chico, the average January per-capita use was 41 percent higher, while average July July use was 88 percent higher, than in Stockton.

Almost all of the flat rate urban water in California consists of residential water in Central Valley cities. Red Bluff, Chico, Sacramento, Davis, Woodland, Modesto, Merced, Fresno, and Bakersfield provide unmetered flat rate water for most, if not all, of their residential customers. Some cities even provide flat-rate water for various commercial or public authority accounts.

For the most part, water used in these communities is available for reuse. Thus, water conservation is not as beneficial as it is in areas where water flows to an unusable source. Still, there are considerable advantages to water conservation. Operating costs to treat and deliver water may be reduced as less is delivered. Likewise, operating costs for sewage treatment may decrease. Costly expansion of water and sewer systems will not be needed as soon.

Although there are benefits to be gained by the water district and customers in having a metered system, the necessary cost of buying and installing meters on existing homes is rather high--from $150 to $300 per house. Therefore, only a relatively few small water districts in California have programs of mandatory conversions to meters. The El Dorado Irrigation District requires that all homes in El Dorado Hills be metered within three years, at homeowner expense. This is being done because a district study revealed that it costs over $30 per month to supply water to a typical home in El Dorado Hills.

Although metering existing homes may be expensive, installing meters at the time of construction is not. It costs only about $60 more to provide a new home with metered water service instead of unmetered service. In most cases, this cost will be recovered in savings in the utility's supply and delivery costs in three or four years. Some utilities which have traditionally had unmetered residential accounts now require all new construction to be metered. Hanford, in Kings County and Red Bluff, in Tehama County, have required metering of new homes since 1976. Both cities report no significant public reaction against these ordinances. Rohnert Park, in Sonoma County requires that meter vaults be installed in new construction to facilitate future metering.

An important benefit of reduced water use due to rate structures which charge based on the quantity consumed in new developments is that the reductions in water demand could occur "at the margin." In other words, although the average cost of supplying residential water in a city might be $100 an acre-foot, the incremental cost of supplying new water to new developments could be $150, even $200 per acre-foot. Reduced water demand due to metering will mean that costly enlargements of the distribution system could be postponed, and that less water will be required from expensive new sources.

Device Distribution

Retrofitting residential toilets and showers with devices to reduce water use is an effective conservation measure, and promotion of retrofitting has become quite popular with many water agencies. These programs are attractive to utilities because water use is reduced immediately. The utility should offer devices again every few years in order to maintain high retention rates because the devices may wear out or be removed. In addition to the direct benefit of reduced water use, distribution programs publicize water conservation and heighten public awareness of its importance.

There are significant benefits for people who use the devices in terms of reduced water use and reduced energy use. Both of these can save consumers money. The reduction in energy used to heat shower water is particularly attractive, outweighing all other program benefits.

Decisions regarding the type of devices to be distributed and the distribution method are interrelated. Small light devices may be mailed or distributed door-to-door. Heavy or bulky items are best distributed in a manner that requires less handling. At least four methods of distribution may be used: kit request, depot, mass mailing, and installation.

Kit Request Program. In a kit request program each household in the service area is provided with a card to fill out and return if devices are desired. This can be mailed with an appropriate brochure in a water or power billing. This approach results in a high level of public awareness. Kits are mailed to those households that fill out and return the request cards. This type of program has very little waste because kits are sent only to those who actually request them. The most appropriate devices are those that can be mailed easily: displacement bags, shower flow restrictors, dye tablets for toilet leak detection, and informational literature.

Depot Method. Another distribution alternative is the depot method, in which householders pick up kits at depots or distribution points established in convenient locations. As with the kit request method, few kits are wasted since some customer effort is required to obtain them. The direct public contact of depot distribution may increase conservation awareness. However, depot distribution requires user effort and depot staffing. Bulky or heavy items such as displacement bottles or showerheads may be distributed at depots.

Mass Mailing. Very high public awareness can be achieved with a mass mailing program, in which conservation kits are mailed to all residences in the program area. However, since many residents will not install the devices, many kits will be wasted. As in a kit request program, the devices should be light and easy to mail. A variation of this method is to have staff members or a private delivery service distribute kits to each household. Wasted kits can be reduced by leaving kits only at the homes where residents wish to use them.

Installation Programs. By far the most expensive type of distribution program is one in which volunteers or paid workers install retrofit devices at no charge to the householder. This type of program may expose the program agency to liability for damage to plumbing. However, free installation programs have the very highest installation rates and offer opportunities for heightened public awareness through direct contact. Device distribution programs are described in greater detail in a Department guidebook, How To Do A Residential Retrofit Program.

Test Programs

Various devices and distribution methods were tested by DWR in a study conducted in 1977. The program was carried out under the authorization of Assembly Bill 380 (Chapter 28, Statutes of 1977), which appropriated $600,000 to meet the following goals:

1. To find out whether a significant amount of water and energy could be saved by installing water saving devices in dwellings.

2. To determine which methods of distribution are most successful and cost-effective.

3. To evaluate the relative merits of offering devices free or selling them, and to determine which kinds of devices are most acceptable to the public.

4. To determine the feasibility of distributing water saving devices throughout the State.

In addition to the money provided by the bill, the Department allocated $100,000 to the project, and the California Energy Commission contributed $50,000.

One-hundred thirty-one types of water saving devices for toilets and showers were tested in a laboratory set up especially for the purpose. Several types of devices were selected for use in six pilot programs conducted in communities around the state. Toilet devices used in the programs were water dams, plastic water displacement bottles, plastic water displacement bags, toilet float adjusters, adjustable flush valves, flush valve controls, and leak detecting dye tablets. Three types of shower flow-reducing devices were also used - internal and external flow restrictors and low-flow shower heads. In one area, a faucet flow reducer was used as well.

More than 500,000 devices were distributed. About 1,200 people took part in the administration, distribution, and - in some areas - installation in the six pilot areas. About 180,000 households received devices. Installation rates and satisfaction with the retrofit devices were determined by telephone surveys in each program area. The program is summarized in Table 5

This massive effort resulted in considerable direct benefits. During that critical drought period, the in-home reductions in water use from devices installed in the six pilot areas was estimated to be 4,200 acre-feet per year. The annual energy savings (mostly reductions in hot water needed for showers) was estimated as being equivalent to the energy produced by 76,000 barrels of oil. As important as these savings in water and energy were, the information gained from the program was even more valuable. Potential water and energy savings from the use of devices were documented and measured in laboratory tests. Various methods of distribution were tried and compared, and public acceptability of various devices was determined. The program was documented in DWR Bulletin 191, A Pilot Water Conservation Program, published in October 1978. Additional detail was published in eight separate appendices.

Based upon the results of this study the Department concluded that a program to offer conservation devices to 7.5 mil-

Table 5. Water Conservation Device Distribution Program

Pilot Area	Type of Community	Number of Households	Water Supply Condition	Method of Kit Distribution	Free/ Purchase	Type of Promotion Campaign
San Diego Metropolitan Area	Urban	370,000	No rationing	Mass; door-to-door with personal contact; depot	Free	Information post cards, paid ads, public relations activities
Santa Cruz County	Urban and rural	60,400	45 percent of County had rationing ordinances to achieve up to 30 percent reduction	Depot and home delivery with free installation upon request	Free	Public relations activities,home canvassing
City of Sanger	Small agricultural community	3,000	No rationing	Home delivery upon request	Free	Information post cards
El Dorado Irrigation District	Small urban and rural	13,300	Pricing structure and rationing ordinance designed to achieve 50 percent overall reduction	Depot	Purchase	Leaflets, paid ads in newspapers, public relations activities
City of El Segundo	Urban	6,000	Water rationed. Ordinance designed to achieve 10 percent reduction	Mobile sales depot	Purchase	Paid ads in newspapers, mass mailing, newsletters
Community of Oak Park	Small suburban	753	No rationing	Free installation service	Free	Public relations activities

lion households statewide would be feasible. (There are actually about 8.5 million households in California but nearly a million of these were built after the state's water-conserving shower, faucet, and toilet laws were enacted in 1978.) The pilot programs had shown that offering devices free rather than selling them resulted in a much higher installation rate, and that the greatest savings per program dollar would be achieved through door to door delivery of devices. With these lessons in mind, a standard household retrofit kit was developed, which consisted of a toilet tank displacement bag, shower flow restrictors, dye tablets for toilet testing, with installation instructions and general water conservation information.

Statewide Retrofit Program

Funding to begin a statewide retrofit effort was received in 1979 when the Renewable Resources Investment Fund was created by the legislature to protect and enhance California's natural resources. With water an essential and scarce resource in the state, part of the fund was committed to a plan to offer toilet and shower retrofit devices to all California households.

The first phase of the retrofit program took place in Santa Barbara County in the spring of 1980. A new method of distribution, mass mailing, was being considered. Since this method had not been tested in the pilot studies, the Santa Barbara program was designed to compare the effectiveness of mass mailing with the most cost effective large-scale delivery method used earlier - hand delivery.

One-hundred ten thousand households received kits in Santa Barbara County through the two delivery methods. Findings of a follow-up study showed clearly that mail delivery was far more effective than hand delivery. In areas where kits were received in the mail, 35 percent of the households installed the toilet bag, 18 percent used the shower flow restrictors, and 21 percent tested toilets with the dye tablets. In areas where kits were to be hand delivered, only 8 percent of the households used the toilet bags, 5 percent retrofitted showers, and 5 percent checked for toilet leaks. Much of the difference was attributed to poor coverage by the private delivery crews; many households never received a kit.

The distribution of household retrofit devices in Santa Barbara County was heavily supported with advertising, public relations, and an in-school education program to increase public awareness and commitment to water conservation. The total cost for the Santa Barbara program was less than $200,000.

First year savings to consumers in water and energy bills was estimated to be over $650,000 based on laboratory studies.

Because of the greater success of the mail delivery in Santa Barbara, this method has been used by the Department in all subsequent large scale programs. Working cooperatively with local water agencies, sewer districts, schools, and city and county governments, the Department has participated in programs which mailed kits to households in the Humboldt Bay area, Santa Clara, Orange, and Ventura Counties, and the cities of Sacramento, Stockton, Fresno. The City of Los Angeles also conducted a program in which kits were mailed to every household in the City.

Other state retrofit programs have concentrated on specific target groups. In 1981, the State Water Resources Control Board funded a household retrofit program in areas of the state where sewage treatment plants were nearing, or had already reached, capacity. Nineteen areas were selected, totalling 286,000 households. The Department

A Water Conservation Kit

worked with local sanitation districts who also provided some funding, to carry out the programs. These efforts were patterned after other Department programs, with in-school education, advertising, and public relations playing important roles.

Since 1977, the Department has participated in retrofit programs which have made water conservation devices available to four million California households. Despite this very active role, the Department was not the first nor has it been the only agency to carry out retrofit programs. Even before the 1976-77 drought, some communities had distributed conservation devices. These programs were often motivated by local conditions, such as a lack of adequate developed water supplies, or sewage treatment plants that were approaching capacity. During the drought, many communities established retrofit programs, some even requiring toilets and showers to be retrofitted. Other retrofit programs have been established as part of comprehensive natural resource management efforts.

Follow-up surveys conducted in areas where devices have been distributed earlier can give some idea of the long-range effect of retrofit programs. On the average, 35 percent of the households have installed toilet devices in Department of Water Resources program areas, and 17 percent of the households have used shower flow restrictors. Twenty months after the San Diego program, 69 percent of the households that had toilet devices installed in 1977 reported they were still in place, and 88 percent of the households that had installed shower flow reducers reported they were still being used. One way to help keep retention rates high and maintain the public's conservation awareness is to follow a mailout retrofit program with a kit request program every few years. This way, devices are not wasted by being sent to households that have already been retrofitted, nonretrofitted households have another opportunity to obtain devices, and general conservation information can be sent to all households along with the kit request card.

Public Information

Perhaps the single most important aspect of an urban water conservation effort is a public information program. An information program can be used to increase awareness of water and the need to conserve. It can help citizens understand where water comes from, why it is valuable, how to use less of it, and what the benefits of water conservation are. Public information programs are almost essential to promote specific programs, such as the distribution of water conservation kits, and ongoing information programs help to maintain an awareness of water conservation.

The variety of methods used to disseminate information is almost endless. Some of the simplest and most visible media are posters, bumper stickers, lapel buttons, and billboards. Newspaper advertisements and public service announcements on radio or television can carry more information. Brochures and bill stuffers containing a great deal of information on conservation can be delivered directly to customers. Bills can also compare this year's and last year's use to help customers monitor their water consumption. Newsletters, press conferences, and news releases can also be used to disseminate information.

Brochures

Water agencies can purchase or develop a general water conservation brochure, a landscape brochure and plant list, and brochures and handouts for specific water users such as hospitals, laundromats. These materials should be distributed regularly. Literature can also be distributed at public speaking engagements, events such as fairs and expositions, and at locations throughout the community such as libraries, environmental organization offices, schools, and water agency offices. Brochures may also be mailed directly to targeted areas, such as new residential areas or business areas. Water agencies could encourage energy utilities to distribute water and energy conservation literature in their bills or through their other outreach efforts.

Agencies with postcard or computer sealed bills can print a brief water conservation message on the bill. Any agency unable to print messages can stamp a logo or slogan on the bill or envelope. Providing information to customers on their previous year's use for the same billing period helps increase their awareness of water use patterns and may even prevent an increase in water use. Where possible, water agencies might provide the previous year's water use information for the same billing period on all water bills. Agencies could prepare a newspaper article or bill stuffer approximately once a year, explaining how consumers can measure their conservation.

A water agency can either design and print its own literature, hire a consultant, or purchase brochures from Department of Water Resources, the American Water Works Association, the Association of California Water Agencies or other local water agencies. The Department and local agencies can assist in providing ideas for the content, such as residential "self-help" home audit check lists and mailing of literature. The three types of recommended brochures are described below.

General. A general water conservation brochure can be used for all urban water users including residential, commercial, public, and industrial. It preferably will include watersaving tips on indoor and outdoor water use, potential energy savings and background information on the need for water conservation from a statewide and local perspective. It could also contain sources for additional water conservaton information.

Landscape. A well designed brochure will include landscape water conservation tips, a low water-using plant list appropriate to the area, ideas for designing low water-using landscapes, and a list of water conservation landscapes, arboretums, and nurseries in the area. The audience for the landscape brochure is the homeowner, landscape professionals, nurseries, schools, community organizations and local government agencies such as planning, parks and public works departments.

The landscape brochure, if not designed by the agency, should be purchased from an agency in an area of similar climate so that the landscape information and plant list are suited to the local climate and environmental conditions.

DWR can serve as a resource center, providing reference material on low water-using plant materials, appropriate irrigation systems, concepts of water-conserving landscapes, and a list of growers that can supply low water-uisng plants.

Specific Water Use. Water agencies can also provide informational bulletins on water conservation measures appropriate to specific commercial, public and industrial water users in their area. Various water agencies have developed water conservation bulletins for commercial buildings, restaurants, golf courses, health care facilities, laundries and linen suppliers, hotels, schools and colleges, beverage industries, and food processing industries.

Public Relations

Water agencies can promote water conservation through television, radio, and newspaper advertising when those forms of communication reach the majority of the intended service areas, without extensive overlap into neighboring service areas.

The Department has television and radio public service announcements that water agencies can encourage their local stations to use. Press releases can be prepared to publicize water conservation events such as a device distribution program or major speaking engagements.

Agencies can also provide updated information on water supply and use to local newspapers, television and radio stations for use as filler items.

In addition, water utilities can ask businesses and industries to post water conservation messages in restrooms and other areas and help with water conservation programs. Agencies may want to involve local businesses in financing certain water conservation programs. Businesses and industries should also be encouraged to let the public know what they are doing to save water in order to demonstrate the level of community involvement. Water conservation displays are another means of informing the public about water conservation. The Department will loan water conservation displays on a temporary basis.

The division of responsibility for advertising and promotional campaigns will vary between wholesale and retail agencies in the State. In locations where several service areas receive the same newspapers, and television or radio stations, the advertising program will usually be the responsibility of the wholesaler. Advertising should be coordinated when more than one water agency service area is covered by the same television, radio or newspaper.

Public Speaking Presentations

Presentations on water conservation are a useful part of a conservation program. Water conservation information can be integrated into presentations that cover other subjects. Water agencies may want to appoint a knowledgeable representative who will be responsible for public speaking in the local area.

Movies and slide shows can be designed or acquired by the agency to assist the speakers and to be loaned to other agencies or organizations. The Department has a landscape slide show, and Santa Clara Valley Water District, East Bay Municipal Utility District, and the California Association of Nurserymen have developed a landscape film that is available through East Bay MUD.

The public speaking program can be publicized to local government agencies, community organizations, professional organizations, businesses, and schools. Water agencies can also seek speaking engagements on local radio and television shows to present information on the local water situation and conservation programs. Workshops and seminars can be organized and cosponsored by appropriate organizations. Agencies can advertise the availability of speakers, movies and slide shows on water conservation.

Most of a water agency's public information efforts will probably be directed toward residential water users, since residential use accounts for such a large part of urban water use. However, it is often worthwhile to include other audiences in an information program as well. Most commercial uses of water are similar to residential uses, landscape irrigation and toilet flushing being major components. Small modifications in some public information materials may make them suitable for commercial customers. If a significant part of an agency's water deliveries go to a few major industrial users, working individually with these customers may also be beneficial.

An important step in the development of a water conservation public information program is the development of the program goal. Promotion of a specific effort, such as the distribution of kits, will call for a short intensive campaign using such media as billboards, press releases, and news conferences. Long-term support of a comprehensive water conservation program should rely on several media so that the conservation message is reinforced. Such a program might include bill stuffers, news releases, public service announcements, a newsletter, and advertisements for specific campaigns.

It is very difficult to quantify the reductions in water use resulting from public information programs. Despite this, most water managers agree that conservation does result. As an example, during the 1976-77 drought, some California counties were forced to reduce water use by more than 50 percent. Although water conservation devices were distributed, they could account for only part of the conserved water. The majority came from changes in water use habits brought on by people's perception of the need to save. This perception was developed by the massive public information efforts of water agencies and news media.

Except during a drought or other water crisis, when mandatory restrictions are imposed, public information efforts will be less successful. Still, an increasing public awareness of water and the resulting changes in water use habits can reduce water use.

The costs associated with a public information effort will vary greatly according to the type of program. A short campaign for a specific purpose, such as publicizing a kit program, may rely largely on free news coverage supplemented with paid newspaper advertisements and free public service announcements. A more comprehensive program can be carried out more economically by purchasing materials prepared by the Department or a local agency.

DWR Information Program

The Department has had an ambitious water conservation public information program since 1976. More than twenty radio and television public service announcements have been produced. Information sheets, checklists, and brochures on conserving water in the household have been published. Many of these are available to local agencies in quantity or as camera-ready copy. More detailed information on landscape water conservation is available in DWR Bulletin 209, Plants for California Landscapes: A Catalog of Drought Tolerant Plants, September 1979, and DWR Bulletin 213, Captured Rainfall: Small Scale Water Supply Systems, May 1981. Also, a water conservation newsletter, Conserve, is distributed to about 3,500 readers of diverse interests. Each issue covers water conservation efforts in California and the nation. A resource center of water conservation research and public information materials has been developed within the Office of Water Conservation. In addition to books, periodicals, and other publications, the center includes films and video tapes. Displays on agricultural, urban, and landscape conservation have been developed for conferences and fairs.

More technical information is available for specific water users. A guidebook on how to conduct a residential retrofit program has been published for water agencies and local governments. The Department has provided forums for the exchange of information on conservation by sponsoring conferences on agricultural water conservation, urban water conservation, and industrial water allocation and conservation. An irrigation scheduling guide is available for farmers, and workshops on irrigation scheduling have been held in many parts of the state. Field trips to examine innovative irrigation methods have also been held. The Department regularly advises other state agencies on water conservation. Several state agencies have been able to reduce their water use, setting a good example for other governmental and commercial water users.

Local Information Programs

Dozens of water agencies and local governments in California have strong public information programs as well. A good example is the program of the Three Valleys Municipal Water District (TVMWD) in Los Angeles County. This agency is a water wholesaler, purchasing water from the Metropolitan Water District of Southern California (MWD) and in turn selling it to nine retail water agencies that serve 360,000 people. TVMWD has had a public information office since 1973, and the agency's public information focus has turned increasingly to water conservation. Materials on conservation produced by the agency include lapel buttons, posters, and a household conservation checklist. Several pieces of children's educational materials have also been prepared. A semiannual newsletter with strong emphasis on conservation is also published. It has a circulation of 93,000 and a cost of $12,500 per issue.

In addition, TVMWD distributes materials that it obtains from other agencies. TVMWD provides brochures on general household conservation and water-conserving landscapes, bumper stickers, bill stuffers, and children's educational materials. The Department of Water Resources provides brochures and children's educational materials. TVMWD also obtains public information materials from the American Water Works Association.

Many of the materials produced or obtained by TVMWD are distributed by the public information offices of the retail agencies it serves.

Landscape Programs

Because nearly half of the water used by households in California is used outdoors for watering gardens, low water use landscape programs offer a great potential for reducing water use.

There are many different ways to provide information on landscape water conservation. In addition to the familiar brochures, slideshows, public service announcements, and speaking engagements, information on efficient use of landscape irrigation water may be conveyed through demonstration gardens and cooperative programs with nurseries or colleges. Experience is accumulating on how to conduct these programs most effectively.

Demonstration Gardens

The most popular landscape education effort initiated by communities has been establishment of demonstration water-conserving gardens. One of the first was planted by the Department in cooperation with the State Office of Appropriate Technology in Sacramento in 1977. The garden serves as a small public park in a residential area. People considering planting a water-conserving garden can visit and see first-hand the variety of plants available. All plants are labeled for easy identification, and efficient irrigation systems are in use and available for inspection. The landscape serves as an outdoor classroom for lectures on low water-use gardening conducted by community groups and colleges. Finally, the garden serves as a setting for television news spots on water issues.

The first garden was so well received that the Department has assisted in establishing six more around the State. Many other agencies have planted demonstration gardens as well, including the Los Angeles Department of Water and Power, The Metropolitan Water District of Southern California, the San Diego County Water Authority, the Marin Municipal Water District, the California Water Service Company, and the Irvine Ranch Water District.

Local governments or water agencies may be able to establish demonstration gardens at new public buildings or schools. Since these areas would be landscaped and maintained anyway, the only additional costs will be for such things as plant identification signs. These costs will soon be offset by savings in labor, water, and fertilizer. Placing demonstration landscapes around busy public buildings also sets a good example and assures that the demonstration gardens will have high visibility.

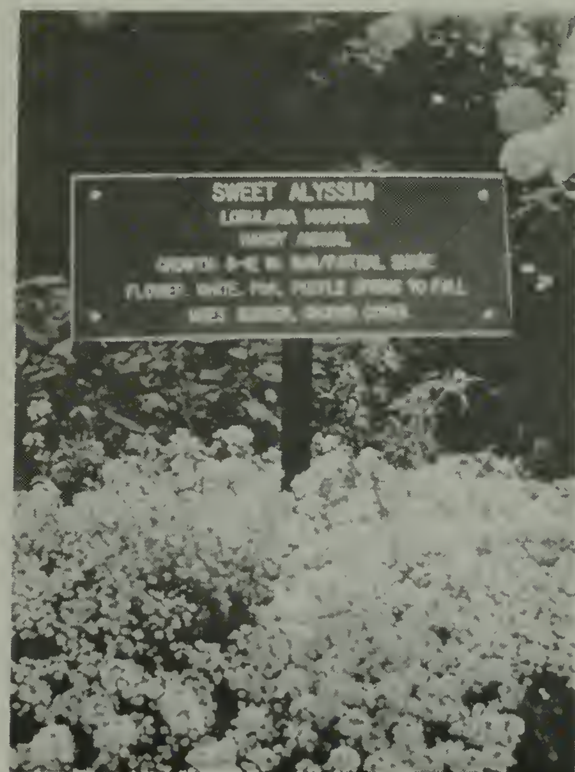
The Denver Water Department has devised a unique and inexpensive way to establish a garden. The agency worked with local landscape architects and contractors, nurseries, and suppliers of irrigation equipment to establish a demonstration garden at the agency's headquarters. All labor and materials were provided free of charge. The Water Department has produced a brochure describing the garden and all participating businesses are mentioned in it. These businesses now stock the water-conserving plants and irrigation systems used in the garden.

A demonstration garden in the community will complement other public information programs aimed at reducing outdoor water use. Some people may learn of a garden in their city through a brochure on landscape water conservation. Others who are considering converting their landscapes or planting new low water-use landscapes, after reading an article on the topic in a local newspaper or magazine, may be persuaded to do so after seeing the colorful low-maintenance plants in a local garden.

Other Landscape Programs

Other landscape programs should accomplish the same things that demonstration gardens do: introduce the concept of a water conserving garden, convince the public to establish water conserving gardens, and provide the information necessary to do this. The appeal of any landscape is largely visual, so visual media best introduce the concept of low water-using landscaping and persuade people to plant such gardens. Televised public service announcements and short news spots can do this well.

Slide shows presented by water agency speakers and brochures with color photographs can also be persuasive, while at the same time containing considerable detail on how to actually establish low water-use gardens. Public information programs involving some or all of these methods have been established in San Diego, Los Angeles, Santa Barbara, Claremont, and Sacramento. The Department has produced a slide show on landscape water conservation and two 30-second television public service announcements, all of which are avail-



Scenes from a Demonstration Garden

able to water agencies and local governments for use in water conservation programs.

Another possible program is to sponsor an awards program for water conserving developments. Different categories for the awards could include single family homes, and multifamily, commercial and industrial developments. Agencies can determine what type of developments in their area they wish to include in the awards program.

Extensive publicity may encourage contestant participation. The winning designs or developments could be submitted to appropriate professional journals and magazines.

Some water agencies and local governments have found that cooperative landscape water conservation programs initiated with other organizations can be successful. By working with professional horticultural organizations, commercial nurseries, and universities, local agencies can share costs and take advantage of the expertise of these groups.

Sometimes the audience of a cooperative informational program will be the general public. An example would be a seminar on native plants conducted by a garden club in a water agency's demonstration garden. Many such lectures have taken place in Sacramento's garden, arranged by the community service organization which manages the garden.

Agencies can work with local plant nurseries to encourage the sale of drought-tolerant plants. Agencies can advertise the program with public service announcements, literature or posters and provide plant labels to the nurseries so customers can easily identify drought-tolerant plants. Retail agencies can provide nurseries with water consevation literature to be distributed to customers. While efforts should be made to involve as many nurseries as possible, the program should focus on the largest and most popular nurseries in the service area. To reach the majority of nurseries, local nursery organizations should be contacted.

Other cooperative efforts will have a much narrower focus. Articles in trade journals or workshops for landscape architects will reach relative few people but may influence the design of many large commercial and multi-unit residential landscapes. The American Society of Landscape Architects offers awards for appropriate designs, including water conserving landscapes, and these designs are featured in the Society's publication Landscape Architecture. Major commercial landscape designs with outstanding water conservation elements or other features are also showcased in the publication. Another industry magazine, Grounds Maintenance, has published a major series of articles on water conservation. The California Landscape Contractor's Association has sponsored seminars on low maintenance/ drought resistant plantings and drip irrigation.

Similarly, programs with colleges or universities can help students of horticulture or landscape architecture acquire the knowledge to design and maintain water-efficient landscapes. In San Jose, the University of California Extension offers college courses on appropriate landscape techniques and uses the demonstration garden in a local park for hands-on training. Several other California colleges, including the University of California campuses at Santa Cruz, Davis, and Santa Barbara, have established similar programs using demonstration gardens as teaching tools.

Landscape Ordinances

Landscape water use can be modified with ordinances. A common ordinance regarding the irrigation of existing landscapes is a prohibition of excessive runoff. A more far-reaching ordinance would govern new landscapes, requiring that low water-using landscapes be installed in all new public, commercial, industrial and multi-family home developments. Landscapes which will be used for active recreation, such as playing fields, would normally be exempt.

Generally speaking, the design should: 1) specify low water-using plants when possible; 2) limit turf to action use areas; 3) preserve existing trees and shrubs; 4) include mulching of non-turf landscape; 5) require an efficient irrigation system; and 6) minimize runoff.

Education of School Children

A public information effort may include a program to teach school children about water and its wise use. The goal of an in-school education program is to give school children some knowledge of the water cycle, how water is supplied to cities and farms, why saving water is important, and how to save water. It is hoped that this understanding of water will make children more conscious of water use and help them form life-long water conserving habits.
California's Education Code requires the governing board of each school district to adopt a curriculum that includes the study of resources conservation and environmental protection. This makes an in-school unit on water conservation very appropriate. School districts might not take the lead in establishing such a program; therefore, water agencies will probably need to take the initiative and establish programs, working cooperatively with school districts.

Many utilities begin an educational program for school children in conjunction with some other community water conservation effort such as a residential retrofit program. Coordination of two programs in this way can make both more successful. Children carry their new concern for water conservation home to parents, increasing the installation rate of retrofit devices, and the attention to conservation at home reinforces the conservation lessons at school.

Learning to Use Water Wisely

The most effective conservation education program is one that continues year after year, rather than as a one-time effort. An ongoing program assures that most children in the community will have an opportunity to learn about water and conservation at some point during their schooling, and perhaps even learn increasingly complex concepts about water in a program that encompasses several grades. This type of in-school education can still be coordinated with other utility programs when they occur, with only minor changes in the school programs.

Developing School Programs

There are two main types of in-school education programs that a utility can develop. The nature of the program selected will depend primarily on the utility's purpose in pursuing in-school education and the level of funding available. Some utilities have chosen a direct program of visiting schools and presenting information to students by employing full-or part-time teachers to conduct water conservation lessons. This type of program can be developed rather quickly. However, the speakers may reach only a portion of the students in the community, reducing program effectiveness. In addition, the water agency speakers must be well trained or they may not be as effective as classroom teachers at communicating the desired message. This type of program may require a large commitment of water utility staff time.

Another approach is to supply instructional materials to local school districts and to train teachers to use the materials. This method assures that lessons on water and conservation are delivered by trained professionals and increases the chances that all students at a selected grade level will be reached. This type of program will require more planning, but the total staff time required will probably be less than for a direct speaking program because agency representatives are training only school teachers, not reaching every student directly. This program is probably the most effective type if a water agency intends to make a continuing commitment to an educational program and hopes to instill good long-term water use habits in the community. A water utility with a small education staff and a large service area might particularly consider this approach.

High-quality instructional materials are extremely important for a water conservation education program. The materials may be purchased from an agency that has already developed good materials, or the preparation of suitable materials may be commissioned. Sometimes agencies purchase basic materials and develop supplemental materials on the local water-supply situation. Water agencies should recognize that the development of instructional materials is a very sophisticated process. The text must use a vocabulary understandable to students in the grades where the materials are to be used, and the concepts presented must be appropriate for these students as well. The illustrations should be simple, yet eye-catching. Finally, the finished product should be classroom-tested to confirm its effectiveness. Working closely with classroom teachers throughout development and testing will help assure the production of useful, high-quality materials.

Water utilities should not expect reductions in water consumption immediately following the start of an in-school program. The success of this type of program is best measured by the increase in students' knowledge of water and its use. It will be difficult or impossible to quantify program results in terms of the amount of water saved.

DWR School Programs

In 1976, DWR, in cooperation with the State Department of Education, began preliminary work on the Water Awareness Program -- an in-school education program for elementary school students. The program formally began in September 1977 with a grant from the State's Environmental Protection Program Fund, which is funded by environmental license plate fees. Support was received from the County Superintendents of Schools.

The State's continuing program has two aspects--development or purchase of curriculum materials, and teacher training. Basic curriculum materials used by the Department, consisting of student workbooks and teacher's guides, were developed by the East Bay Municipal Utility District. These include: Water Play, for primary grades; The Official Captain Hydro, for upper elementary; Capitan Tlaloc, the Spanish version of The Official Captain Hydro; and The Further Adventures of Captain Hydro, for junior high. In addition to the basic curriculum materials, the Department developed supplementary materials including Water Is Your Best Friend, a primary teacher's guide; Regional Teacher's Guide Supplements for grades K-8; and The California Water Works And Why It Does..., in English and Spanish, a primer on California water for upper elementary and junior high. Water Fun, a primary unit with teacher's guide developed by the Los Angeles Department of Water and Power, is also used.

The Department attempts to reach the widest possible audience by training teachers to use the materials. Staff members from the Water Awareness Program conduct free workshops throughout the State to train teachers on how to best use the curriculum materials, in addition to explaining the importance of water conservation and the local water supply situation.

The program is promoted with news releases, participation in fairs, mass mailings of promotional materials, and letters to water agencies asking them to join with their schools to support the program and to develop local supplements. The State Department of Education has reinforced these requests with similar mailings to county schools officials.

Another important part of the Department's education program involves helping water agencies and sewer districts to develop their own conservation education programs. Materials and presentations are modified to suit the needs of communities carrying out residential retrofit programs or areas with water supply or sewage capacity problems.

Since 1981-82, the program has offered free curriculum materials. However, several conditions must first be met, including required in-service training for teachers or teacher representatives. In addition, in-kind services are required, such as obtaining approval for the program from the school superintendent, and support and participation from the local water agency; arranging for and coordinating in-service training; estimating numbers of teachers and students; and organizing distribution of curriculum materials to teachers. This arrangement has worked very well, since local agencies must become involved in the program, even though no direct funding is required. This has encouraged both schools and water agencies to begin water conservation education programs.

In five years of operation, the Department's program has reached 733,000 students in grades kindergarten through eight, or over one-fourth of the student population in those grades in California. So far, 24,500 teachers have been trained to present materials on water conservation.

Dozens of water agencies throughout California have also established local in-school education programs, including the Los Angeles Department of Water and Power, the Long Beach Water Department, and Municipal Water District of Orange County, the San Diego Water Authority, the Metropolitan Water District of Southern California, the Sacramento Area Water Works Association, the Santa Clara Valley Water Agency, the California Water Service Company, and the East Bay Municipal Utility District to name but a few.

Several other states and national organizations are also becoming involved in water conservation education, including the American Water Works Association and the states of Pennsylvania, Illinois, and New Jersey.

Emergency Restrictions on Water Use

During periods of serious water shortage, it may be necessary to place special restrictions on water use in order to reduce demand. These restrictions will probably be different from the elements of an ongoing water conservation program in two ways. Unlike the activities of an ongoing, permanent program, special restrictions will be temporary. It is expected that the restrictions end when the water shortage ends. Second, these special restrictions may require significant changes in customers' lifestyles, whereas ongoing programs usually require, at most, minimal changes in behavior or water use habits.

Special restrictions on water use can be voluntary (for example, a water agency's request that residential customers sprinkle their lawns only every third day), but water agencies facing a serious shortage may desire the greater certainty of mandatory restrictions. An optimum emergency program may consist of an agency's regular ongoing conservation programs, mandatory restrictions, plus a plea for those customers who can conserve even more to do so. In any mandatory program proposing a percentage reduction in water usage, the agency should consider past customer use and not penalize those who already use water efficiently.

The reductions in water use achieved with special restrictions may depend on several factors other than the nature of the restrictions themselves, including the type and intensity of previous conservation programs, local climate, types of water use in the community, and how the shortage is perceived by local residents. For instance, if nearly all residences have previously been fitted with toilet and shower retrofit devices, additional savings from a mandatory retrofit program would be small. A community with a great deal of landscape irrigation will probably be able to reduce per-capita use far more than a community that never had high landscape water use.

A vital part of any program of water use restriction is adequate public information. Cooperation with restrictions that cause inconvenience requires that customers believe that a water problem exists, understand the problem, and believe that their conservation efforts are important to alleviate the problem.

Many different types of restrictions may be considered, including prohibitions of specific uses, percentage reductions, and maximum use limits.

Prohibiting specific uses is a conservation strategy that is both easy for consumers to understand and easy to enforce, providing the prohibited uses are highly visible ones such as lawn sprinkling or carwashing. However, these restrictions do not allow consumers to set their own priorities for water use.

In metered areas, percentage reductions in water use or maximum allotments per individual may be imposed. These restrictions allow consumers to use their allotted water as they see fit, but customers may need to monitor their use closely to guard against using too much. If maximum allotments per individual are used, they should be adjusted according to household size. If not, people in households with only one or two people may find it harder to comply than those in larger households because some uses of water, such as landscape irrigation, are not related to the number of people in the household. Percentage reductions may be unfair to some businesses. Laundries, for instance, may have increased water use if people conserve their own allotments by washing clothes away from home.

A water agency's efforts to conserve water will probably continue to reap benefits in reduced water use rates long after a temporary water crisis has ended. Many water-conserving habits formed by consumers will be retained, and use rates may take several years to return to precrisis levels.

The response of California water agencies to drought emergencies is described in DWR Bulletin 206, Impact of Severe Drought in Marin County, California, November 1979, and the Department report The 1976-1977 California Drought: A Review, May 1978.

Plumbing Regulations

Long-term reductions in water use can be achieved through regulations that set efficiency standards for plumbing fixtures. These include flush-volume standards for toilets and urinals, flow-rate limits for showerheads and faucets, self-closing faucets for public restrooms, pressure regulation, and code changes to accommodate European toilets. These regulations require a long period of time to affect water use because only a small proportion of fixtures, those installed in new construction and perhaps replacements for worn-out fixtures, are covered by regulations.

Requirements for fixture efficiency can be adopted at the local or state level. Local ordinances may be more difficult to enforce if surrounding areas have no efficiency requirements or if the requirements vary. State standards are likely to be better publicized and compliance is likely to be higher because uniform requirements apply over a large area.

The adoption of regulations governing fixture water use is likely to be among the least expensive conservation measures that a state or community can take. Research and passage of laws or regulations is not expensive. Publicizing the new regulation is imperative but a directed information program for contractors, inspectors, and fixture vendors should be much less expensive than information programs directed at the general public. An approval and listing process for fixtures that comply with the law could be very expensive, even if no fixture testing is done by the government agency. Some local agencies have relied upon manufacturers and vendors to make water use information available with their products so fixtures that comply are evident and listing is not necessary.

Fixture efficiency standards will be acceptable to the public if water-conserving fixtures function as well as standard fixtures, if the benefits of water efficiency are understood, and if water conserving fixtures cost no more than standard ones. For example, faucet flow rate standards are generally very well accepted. In fact, aerators that reduce flow are standard on most faucets because they reduce splashing.

Consumers may notice a difference between standard and low-flow showerheads but low-flow heads are generally acceptable. Because low-flow showerheads reduce hot water use, they can result in energy and cost savings for the user. This factor can help to increase consumer acceptance and is sometimes a primary reason for adoption of shower flow standards.

Toilet flush volume standards have been less acceptable to consumers, vendors, and builders. Performance of low-flush toilet models has not been uniformly high. Toilets of good design and precise construction will perform well with a flush volume of 3.5 gallons or less. Standard models that the manufacturer has adjusted to reduce flush volume, or toilets that are not carefully manufactured, may require double flushing to remove solids. New performance standards to test flushing efficiency have recently been developed by the American National Standards Institute (ANSI). These standards provide a tool for assuring that the few unacceptable models are not approved for use and that the many good water-conserving models are available to the public.

Effect on Water Use

The impact of plumbing regulations on a community's water use depends on several factors, including community size, growth rate, and perhaps water quality. A small town experiencing rapid growth could have water-efficient fixtures in a significant proportion of dwellings within a few years of adoption of standards. A larger city, or one with a low rate of new construction, would experience much slower reductions in per-capita use.

If the regulations apply to replacement fixtures, the water-saving impact will depend on the rate at which fixtures are replaced. If water quality is very high, showerheads and faucets may last twenty years or more. In areas with lower water quality, fixture life may average ten years or less, and significant reductions in per-capita use may be achieved in a decade.

Toilet malfunctions are most often corrected by replacing the flushing mechanism rather than the china fixture, which may have a life of 50 years or more. For this reason the impact of toilet replacement on per-capita use will probably be slight.

Some communities have adopted mandatory retrofit ordinances. Most often, retrofit of the toilet and retrofit or replacement of the showerhead are required when a home is sold. Sometimes these measures are required along with other energy conservation measures.

There has been resistance to mandatory retrofit ordinances for several reasons. Realtors have opposed such requirements because they believe that they impede the sale of homes. Consumers have opposed the requirements because it is usually the seller who pays for the retrofit or replacement and the buyer that reaps the benefit of reduced water and energy bills. Finally, some toilets cannot be retrofitted without impairing the flushing performance.

California Laws and Regulations

California's water-conserving fixture laws include maximum flush volume standards for toilets and urinals and maximum flow rate standards for showerheads and kitchen and lavatory faucets. These were among the first statewide water-conserving fixture standards in the nation when they were adopted in 1976 and 1977.

The state's low-flush toilet law was proposed by the Department in 1975. It prohibited the construction of new hotels, motels, apartment houses, and dwellings equipped with tank-type water closets using more than an average of 3-1/2 gallons per flush. The measure was signed into law in 1976 as Section 17921.3 of the Health and Safety Code and became effective January 1, 1978.

In 1981 the low flush toilet law was expanded to include virtually all toilets installed in California, and urinals as well. It was signed into law in 1982 with an effective date of January 1, 1983.

The State Department of Housing and Community Development (HCD) has the responsibility to maintain a list of acceptable water closets and urinals. The list includes water closets which have been manufactured and tested in accordance with American National Standards Institute (ANSI) Standard A112.19.2 and which have been certified by the manufacturer to use not more than an average of 3-1/2 gallons per flush. There is no such ANSI standard for urinals.

Maximum flow rates for showerheads, lavatory faucets, and sink faucets were adopted in 1977 by the California Energy Resources Conservation and Development Commission (Energy Commission). The regulations became effective on December 22, 1978, but provided a one year grace period to allow remaining standard fixtures to be sold. The regulations were adopted by the Energy Commission to lower energy consumption by reducing the use of heated water. The Department recognized the water conservation potential of low-flow fixtures and strongly supported the regulations because they would save both water and energy.

Regulations concerning low-flow fixtures are found in two parts of the California Administrative Code. Sections of the Appliance Efficiency Regulations in Title 20 specify maximum flow rates and prohibit the sale in California of fixtures that do not comply. The Energy Building Regulations in Title 24 prohibit the installation of fixtures that do not comply with the flow standards.

The standards originally called for a maximum flow rate of 2.75 gpm for all faucets at pressures of 20 to 80 psig and showerheads at pressures of 20 to 45 psig. The maximum flow for showerheads was 3.00 gpm between 45 and 80 psig.

In 1981 the Energy Commission replaced these standards with ANSI Standard A112.18.1M-1979, which specifies a maximum flow rate of 2.75 gpm for all showerheads and kitchen and lavatory faucets between 20 and 80 psig.

The Energy Commission maintains a list of certified fixtures and carries out a compliance monitoring program to assure that the fixtures being sold in California are water- and energy-conserving.

In 1983 Section 7800 was added to the Government Code. This law requires that lavatories in new public facilities must have metering faucets or hot water faucets that deliver a maximum of 0.5 gpm, as well as devices to limit water temperature to 110°F. The law becomes effective January 1, 1985.

Many other states and localities have adopted regulations governing fixture water use. Most of these contain toilet, showerhead, and faucet regulations similar to California's. Some contain additional provisions. For instance, Pennsylvania recommends 0.5 gpm self-closing lavatory faucets in nonresidential buildings.

CHAPTER III. AGRICULTURAL WATER CONSERVATION

Irrigated agriculture is by far the largest user of water in California, using about 36 million acre-feet annually. This water is used to irrigate some nine million acres of cropland and pasture. This chapter describes the importance of agriculture to California's economy and the complexities of agricultural water use and conservation. Misconceptions many Californian's have about agricultural water use are discussed. Information on how cropping patterns and irrigation practices affect agricultural water use are provided and new surface and pressure irrigation methods and their management are highlighted.

Most of the State's irrigated agricultural land is in the Central Valley. About two million acres are under irrigation in the Sacramento Valley and a further five million acres are under irrigation in the San Joaquin Valley. Another major agricultural area is the Imperial Valley in the southeast corner of the State, where about half a million acres are under irrigation. There are about half a million acres of irrigated land in the valleys of the coast ranges and 400,000 acres in the coastal areas of Southern California. The remaining irrigated land is in various parts of the State, mostly the high mountain valleys near the Oregon border. Irrigated acreage in various parts of the State is shown in Figure 14 and Table 6.

A wide variety of crops are grown in California. The long hot summers of the Central Valley result in high yields of many orchard and field crops. The Sacramento Valley, with its heavy soils and abundant supplies of inexpensive water, is well-suited to the production of rice; one quarter of the irrigated land there is planted in rice. Orchard crops, particularly almonds, walnuts, and prunes are also widely grown in the Sacramento Valley. A wide variety of other crops are grown in the valley, notably tomatoes, wheat, and corn. Agriculture in the San Joaquin Valley is distinguished by the large proportion of acreage devoted to cotton and orchard crops. Over one quarter of the irrigated land there is planted in cotton, mostly in the southern parts of the valley. Many kinds of orchard crops are grown, accounting for 15 percent of irrigated acreage in the valley. Large

Almond Orchard in the San Joaquin Valley

Rice Production in the Sacramento Valley

Figure 14. Irrigated and Urban Lands in California

Table 6. Cropping Patterns in California, 1980

Crop Type	Irrigated Acreage					
	Sacramento Valley	San Joaquin Valley	Coast Ranges	South Coast	Colorado River	Other Areas
	(thousand acres)					
Grain	399	775	14	41	157	99
Rice	491	54	--	--	--	--
Sugar beets	59	105	10	--	36	--
Corn	140	302	--	--	--	--
Other field crops	190	362	55	28	25	6
Alfalfa	105	500	52	14	185	130
Improved pasture	284	368	30	20	18	161
Meadow pasture	75	--	--	--	--	85
Tomatoes	108	98	15	--	--	--
Other truck crops	32	201	286	90	119	20
Almonds, Pistachios	94	313	--	--	--	--
Other Deciduous trees	178	299	42	5	1	11
Subtropical orchards	14	174	12	176	33	--
Grapes	7	539	81	18	10	28
Cotton	--	1436	--	--	109	--
Total	2,176	5,526	597	392	693	540

This table indicates total crop acreages. Because some land is double-cropped, the acreages of irrigated land is slightly lower than those shown in the table.

Source: The California Water Plan: Projected Use and Available Water Supplies to 2010, Bulletin 160-83, Department of Water Resources, 1983.

acreages are also planted in grapes and alfalfa. Melons and some vegetables are grown in the southern part of the valley and a wide variety of field crops and grains are grown throughout the valley.

The Imperial Valley, with its hot summers and long growing season is particularly suited for the production of cotton and alfalfa. One-third of the irrigated land there is planted in alfalfa. Large acreages are also planted in cotton. The valley's winters are warm enough for the production of several winter vegetables, particularly lettuce. A number of other crops are grown in the Imperial Valley, including sugar beets and wheat.

The milder climate of the valleys of the coast ranges is suitable for the production of many high-valued vegetables and fruits. Nearly half of the irrigated acreage in this area is planted in vegetables, particularly lettuce and broccoli. Most of California's high-quality wine grapes are grown in the coast ranges. Other important crops include strawberries and apples. Some field crops and grains are grown in the coast ranges as well.

Citrus fruits and avocados are the main crops grown in the coastal areas of Southern California. The production of these high-valued crops is made possible by the warm summers and mild winters

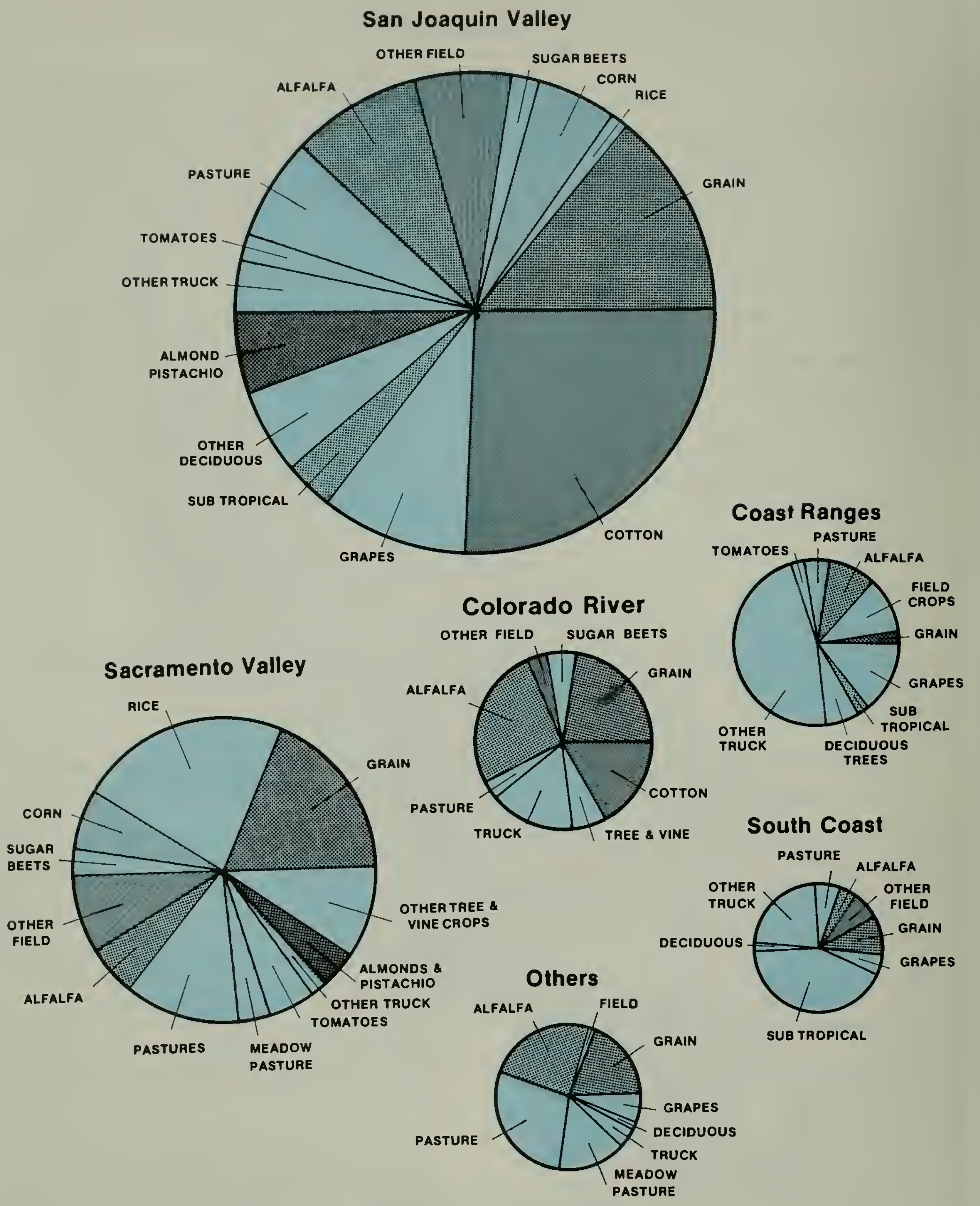


Figure 15. Acreage Planted in Various Crops in California


Young Cauliflower in Coast Range Valley

enjoyed by this area. Nearly half of the irrigated acreage in coastal Southern California is planted in citrus and avocados; much of the remaining acreage is planted in fruits and vegetables, notably strawberries, celery, and lettuce. In contrast with the other agricultural areas in the State, a very small proportion of acreage is planted in field crops and grains. The acreages planted in various crops in the major agricultural areas are shown in Table 6 and Figure 15.

Agriculture is an important source of income in many parts of the State. Although only about 3 percent of California's labor force is directly employed in agriculture, the economy of many of the rural areas of the State is based on producing and processing farm products. For example, in the seven rural counties of the Sacramento Valley, 18,000 of the area's labor force of 86,000 work on farms and a further 2,000 are employed in the industries processing farm products. In the San Joaquin Valley, 138,000 of the region's labor force of 495,000 work on farms and 24,000 work in the food-processing industries.

In order to engage in business, farms and food-processing firms buy goods and services from other businesses in the area. Firms doing business with farms and food-processing firms are also an important source of income in the agricultural areas of the State. In the rural counties of the Sacramento Valley, 1,300 are employed by firms providing agricultural services; many more are employed by dealers in farm equipment and supplies and other firms doing business with farms. Studies of California's economy made by the Department of Water Resources indicate that, depending on the type of crop grown, each hundred jobs in agriculture support a further fifty to one hundred jobs in food-processing firms and other firms doing business with growers. Wages and salaries paid to those working on farms and those working for firms doing business with farms are generally spent in the area creating employment in the retail trade business and so on. This flow of spending through the economy creates more income, generally resulting in a further hundred jobs for every hundred on the farm. When all of these indirect effects are taken into consideration, the contribution made by agriculture to California's economy is larger than might be suggested by the proportion of the State's labor force directly employed in agriculture. Overall, 14 percent of jobs and 15 percent of personal income in the State result directly or indirectly from agriculture.


Young Grape Vineyard

Agricultural Water Use

Agricultural water use differs from urban water use in a number of respects. Most of the water developed for urban use is delivered to households where it is used for a variety of purposes in and around the home. The way in which this water is used is largely the result of individual householders' preferences and habits. In contrast, the manner in which water is used in agriculture is the result of business decisions. Growers base their decisions on what crops to grow on the returns they expect from the sale of the crops and on the costs of growing these crops. Growers' decisions on how much effort to put into managing their irrigation systems are based on an assessment of how the cost of managing a system to apply water more efficiently will be repaid by savings in water and energy costs and increases in crop yields.

Growers generally have more incentive than householders to use water efficiently. Growers' water costs are usually a greater proportion of their total budgets than is the case with households. For example, a typical household in the San Francisco Bay Area with a monthly income of $2,500 might have a monthly water bill of $16, amounting to only half of one percent of its income. In contrast, growers' irrigation costs can often be as high as 25 percent of their total operating costs. Reductions in water applications resulting from better water management can reduce these costs and increase the returns from an operation. Irrigation practice can affect the profitability of an operation even when water costs are low. The yields achieved by a grower may be increased when water is managed carefully; in many cases, better water management can result in savings in fertilizer costs and reductions in the growth of weeds. Water management affects the profitability of a farm operation in many ways, giving growers strong incentives to manage their irrigation systems carefully.

Because the way in which water is used in agriculture is the result of business decisions on the part of growers, agricultural water use is less susceptible to change than is urban water use. A grower's choice of crops is based on an attempt to make the net returns from the operation as large as possible. In deciding which crops to grow and how much acreage to plant in each crop, growers weigh the prices they expect to receive and the yields they feel they can achieve against the costs of growing each crop and the risk associated with marketing the crop. A grower's crop mix is the result of a business decision which takes many factors into consideration; these include the suitability of the grower's land for various crops, the grower's ability to grow particular crops, the risk that the grower is willing to take, crop prices and market conditions, the production costs of the various crops, and the cost and availability of factors of production, such as labor, machinery, and water. Generally speaking, it would be difficult for a grower to change to crops that use less water without reducing profits or increasing the risk of poor yields or unfavorable prices at harvest time.

The case with irrigation practice is similar. A grower's decision on how to manage his irrigation system is based on an attempt to make the operation as profitable as possible. When considering whether to improve his system in some way, a grower will assess the information available to him on how a change in irrigation practice will affect the operation and then compare the cost of improving the system with the savings that can be expected from reduced water and energy use and the increase in returns that can be expected from improved yields. In order to make any decision regarding a change in irrigation practice, a grower needs detailed information on the cost of any new equipment needed, the cost of operating and maintaining this equipment, the extent to which new skills or knowledge are needed in order to manage the improved system effectively, how the change in practice will affect his water and energy use, and how the change in practice will affect the yield and quality of the crop. If this information is not readily available, the grower will be reluctant to consider the change in practice any further. In any case, a grower will proceed with an improvement to an irrigation system only when the information available to him indicates that the change in practice will increase the net returns from his operation.

Application of Water

The amount of water applied in irrigation is determined by the crop grown, the local climate, and the way in which the crop is irrigated. When irrigation water is applied to a field, some of the water is absorbed by the soil and some usually runs off from the end of the field. Part of the water infiltrating into the soil moves downward under gravity and becomes unavailable to the crop; the remaining water is either absorbed by the roots of the plants and eventually discharged to the atmosphere as transpiration, or is lost as evaporation from the moist soil surface. This loss of water to the atmosphere, referred to as evapotranspiration or ET, is the water actually consumed by the crop. The run-off from the end of the field and the water seeping down through the soil as deep percolation is generally available for use elsewhere.

The amount of water consumed by a crop as evapotranspiration is generally between 50 and 80 percent of the total water applied to the field. This evapotranspiration varies widely depending on the physical characteristics of the crop, the length of the growing season, and the local climate. For example, in the San Joaquin Valley, the ET from an acre of alfalfa is about 3.5 acre-feet/year, while the ET from an acre of barley is only about 1.4 acre-feet/year. In the hotter Imperial Valley, the ET from an acre of alfalfa is 5.5 acre-feet/year and the ET from an acre of barley is 2.0 acre-feet/year. The amount of precipitation that is effectively stored in the soil and is used by crops reduces the amount of water that must be applied to meet the crop's evapotranspiration requirements. This is termed the evapotranspiration of applied water (ETAW). Generally speaking, the evapotranspiration from a crop is not affected by the type of irrigation system used or the way in which the system is managed.

Tailwater. In some types of surface systems, some runoff from the end of the field is unavoidable. For example, in furrow systems, water is turned into one end of the field and allowed to flow down the furrows, soaking into the soil as it flows along. Some flow of water right through the furrows is necessary to ensure that the soil in the lower part of the field absorbs sufficient water. Consequently, the irrigator will allow some water to flow across the field and run off as tailwater.

The flow of tailwater can be reduced by various improvements in the way the irrigation system is managed. However, in most parts of the State, water leaving one field as tailwater is available for use further downstream; consequently, a reduction in the flow of tailwater occurring as a result of improved irrigation practice does not generally result in a real saving of water. For example, in Glenn and Colusa Counties, extensive acreages of rice and pasture are irrigated by surface systems. Water is inexpensive and large amounts of tailwater leave individual fields. This tailwater is collected by a system of drainage ditches leading to the Colusa Basin Drainage Canal. Many growers divert some of their water supply from these drainage ditches. If an upstream grower were to reduce the flow of tailwater from his fields, the flow in the drainage ditches would be reduced with the result that downstream growers would have to divert more water from canals. Consequently, reductions in the flow of tailwater in the Sacramento Valley will not result in any real saving of water.

In contrast, tailwater flowing from fields in the Imperial Valley is not generally available for reuse. In most parts of the valley, brackish groundwater comes to within a few feet of the land surface. In order to keep their fields free of this brackish groundwater, growers drain them with systems of underground drains. The growers' drains empty into a system of drainage ditches operated by the Imperial Irrigation District. These ditches also collect the tailwater flowing from growers' fields; the tailwater mixes with the brackish drain water and becomes unsuitable for further use. Because tailwater from farms in Imperial Valley cannot be used again, a reduction in the flow of tailwater there would result in a real saving of water.

Deep Percolation. Some flow of water down through the root zone of the crops is also unavoidable. When making an irrigation, growers apply water to the field so as to ensure that the part of the field absorbing the least water receives sufficient water to bring it up to its full water-holding capacity. The texture of the soil in a field almost always varies from place to place; thus, a grower will apply water long enough for the part of the field absorbing water most slowly to absorb the required amount of water. Other parts of the field will absorb more water than can be held by the soil; this excess water seeps down as deep percolation.

When surface systems are used, the soil near the head ditch is wetter longer than the soil near the tail ditch. Because a grower will run water on the field long enough to bring the soil in the lower part of the field to its full water-holding capacity, the soil near the head ditch will absorb more water than it can hold. Again, this excess water seeps down under gravity as deep percolation.

In some areas, growers purposefully apply excess water to their fields to ensure that minerals do not accumulate in the soil. Irrigation water always contains dissolved minerals; however, crops absorb only a small amount of these minerals, leaving most of the minerals in the irrigation water to accumulate in the soil. In areas with heavy winter rains, such as the Sacramento Valley, these minerals are leached out of the soil after the growing season. But in places such as the San Joaquin Valley and Imperial Valley, where there is little winter rainfall, minerals left from irrigation water can accumulate in the soil year after year, eventually making the soil too saline for agriculture. In these places, some flow of deep percolation water is essential to carry away excess minerals in the irrigation water.

In most areas the flow of deep percolation reaches the water table and recharges groundwater. Consequently, an improvement in irrigation practice which reduces the flow of deep percolation will reduce water applications, but will not necessarily result in a real saving of water. Where water percolating below the root zone enters groundwater of such low quality that it cannot be reused, or is intercepted by drains that transport it to unusable surface water bodies, the water can be considered as irrecoverably lost and reductions in deep percolation can be considered a water supply savings.

New Varieties of Crops

Another possible response to problems with the cost and availability of water might be for growers to change to new varieties of existing crops or even new crops. In the past few decades, crop yields have dramatically increased, due in part to the efforts of plant breeders who developed new varieties that could produce more marketable crops than previous varieties. The traditional objectives in plant breeding have been, and still are, to develop and implement a breeding program to add some desirable characteristics to an existing plant variety, including increased resistance to a particular disease, increased resistance to insects, improved fruit quality, shorter stature, shorter growing season, and so on.

In contrast, relatively little has been accomplished in breeding specifically for drought avoidance or drought tolerance. Drought avoidance is an important factor in areas with well-defined wet and dry seasons. A plant can avoid drought by completing its life cycle, or the major portion of it, before the dry season normally begins. Also, drought avoidance can occur because of physical characteristics that reduce transpiration or increase water absorption. Drought tolerance is more important in areas of restricted irrigation and uncertain rainfall. This factor involves physiological mechanisms within the plant which enable it to withstand severe moisture stress and still produce enough protein and maintain phytosynthesis above the minimum level to survive. In either case, there are many who believe that breeding for drought tolerance and/or avoidance may not provide economically acceptable yields.

There is a major concern with physiological modifications of plants at the stomata. The major loss of water from a crop is through the leaves during normal transpiration. Closing of the stomata to regulate water vapor loss also restricts carbon dioxide entry, and so could result in reduced yields. There is a lack of scientific evidence that breeding for physiological modifications will increase crop yields or the stability of crop yields under stress.

For these reasons, many crop breeders have not undertaken breeding programs to develop specifically drought-tolerant or drought-avoidance varieties. This does not minimize the need for more research on the characteristics of plants associated with tolerance to water stress.

Research to delineate the response of plants to water stress is still an emerging discipline. Planned programs specifically to breed for drought tolerance are still in their infancy. For example, only recently has the U. S. Department of Agriculture established a laboratory at Texas Tech. University to deal specifically with plant stress.

Two good examples of recent developments of crops that can use less water than those grown previously are rice and cotton. The developments for both have been in the form of shortening the growing season.

Genetic breakthroughs in rice breeding have produced a variety of rice that will be suitable for a grower's farming operation and that will meet exacting market demands. Growers can select a short, medium, or long-growing variety, coupled with a short, medium, or tall plant height. An important characteristic of the new varieties is the shorter growing season. Growers always try to plant rice as early as possible, so that the crop can be harvested before the rainy season begins about mid-October. Harvesting in September would not only reduce the possibility of a difficult wet harvest but also reduce water use.

Several years ago, at the U. S. Department of Agriculture's Shafter Cotton Research Station, Dr. V. T. Walhood experimented with narrow-row cotton. He was instrumental in developing a new cultural practice of planting the existing cotton varieties at a closer spacing. The narrow plant spacing results in an increased rate of maturation so the growing season can be shortened by a month or more, reducing the ETAW, while still maintaining the production levels of conventionally-spaced cotton. However, by not reducing the growing season, the narrow-row cotton can produce more cotton than conventionally-spaced cotton. Also, the ETAW of narrow-row cotton becomes the same or more than conventionally-spaced cotton. In the southern San Joaquin Valley, many growers are using the narrow-row planting practice, with the majority irrigating for maximum production.

Irrigation Practice

Irrigation water is applied to crops by two different kinds of systems: surface, or gravity, systems and pressure systems. This section describes various types of surface and pressure irrigation methods and their management. In surface systems, the water is turned into the field and allowed to flow across the field, infiltrating into the soil as it flows along. Thus, the water is distributed across the field by flowing across the soil surface. In pressure systems, the water is distributed across the field by being pumped through a system of pipes or hoses. The water is applied to the soil through sprinkler nozzles or is allowed to drip onto the soil surface through outlets called emitters. The acreages irrigated by the different irrigation methods is shown in Table 7 and Figure 16.

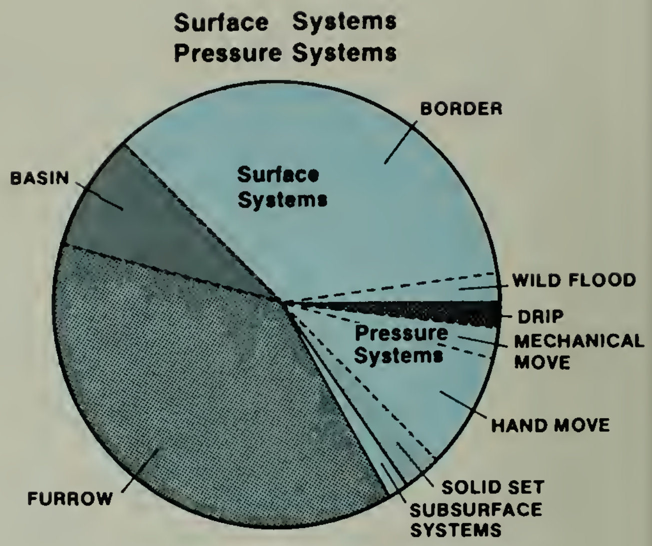


Figure 16. Irrigation Methods Used in California

Table 7. Irrigation Methods Used in California

Region	1980 Irrigated Crop Acreage	Surface Systems: Wild Flood	Border	Basin	Furrow	Total	Pressure Systems: Solid Set	Hand Move	Mechanical Move	Drip Systems	Total
	(thousand acres)										
Sacramento Valley	2,095	100	750	410	520	1,780	70	170	70	5	315
San Joaquin Valley	5,480	5	1,860	255	2,430	4,550	145	585	85	135	930
Coastal Ranges	600	--	30	5	310	345	95	120	30	20	255
South Coast	390	--	10	--	85	95	60	140	--	95	295
Colorado River	690	--	410	35	240	685	--	--	--	5	5
Other Areas	540	155	150	25	15	345	25	40	130	--	195
Total	9,795	260	3,210	730	3,600	7,800	395	1,035	305	260	1,995
Percent	100	3	33	7	36	79	4	10	3	3	20

No data shown for less than 3,000 acres.
Estimates based upon information provided by the U.C. Cooperative Extension Service. In the case of dual irrigation systems (for example, where sprinklers are used for leaching before planting and a furrow system is used for regular irrigation), only the principal irrigation system is indicated.
Excludes approximately 125,000 acres in the Delta irrigated by subsurface seepage.

Source: The California Water Plan: Projected Use and Available of Water Supplies to 2010, Bulletin 160-83, Department of Water Resources, 1983.

Surface Systems

About 80 percent of the irrigated land in California is irrigated with surface, or gravity systems. Most of the crops grown under surface irrigation are irrigated by graded furrow systems. In these systems, water is siphoned from a head ditch running across the upper end of the field into furrows running along the length of the field between the rows of plants. The water then flows down the furrow, soaking into the soil as it flows along. Some of the water flowing down the furrow reaches the lower end of the field, where it is collected by a tail ditch. The tail ditch takes this surplus water, or tailwater, away for use on another field or discharge into a watercourse. In some cases, the tailwater is collected in a pond and pumped back up to the head ditch for reuse. Water is allowed to flow into the furrows until the soil has been wetted long enough for it to absorb the required amount of water. Figure 17 shows the operation of a furrow system.

Preirrigation Using Siphon Tubes on a Furrow System

A recent development in furrow systems is the use of gated pipes to apply the water to the furrows. When this method is used, water is delivered to the field by a pipe running across the head of the field, rather than a head ditch. Water is introduced into the furrows by gates

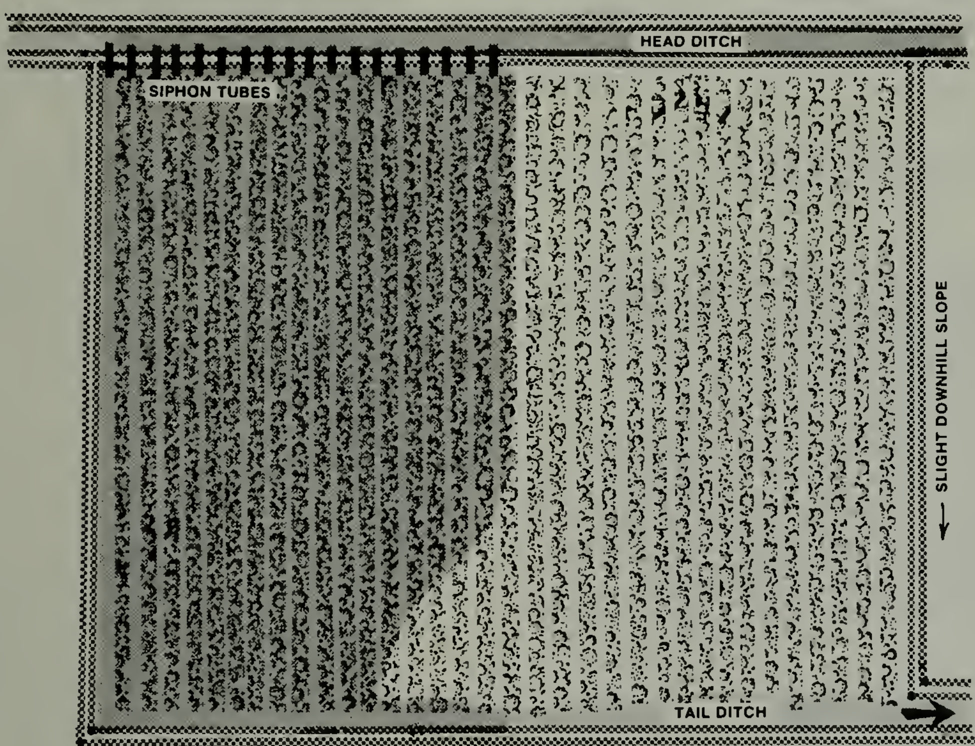


Figure 17. Water Application by Furrow Irrigation

in the side of the pipe. This method allows a closer control of the flow of water into the furrows than is possible with siphon tubes.

When the crop will not be harmed by a complete flooding of the soil surface, savings in labor costs can be achieved by using border strip irrigation (see Figure 18). When these systems are used, the soil surface is formed into strips separated by low berms. These strips slope gently from the upper end of the field to the lower end of the field, where there is usually a ditch for the collection of tailwater. The water is released into the strip by means of a gate or a valve, whereupon it spreads across the width of the strip and flows down the strip toward the tail ditch. The gate is closed when the water has advanced about two-thirds of the way down the field. The water continues to flow down the strip, wetting the entire length of the field. The labor costs of border strip systems are lower than those of furrow systems because water is turned into the field by opening a small number of gates rather than placing a siphon tube in every furrow.

In areas where it is possible to level the land completely, level basin systems are used (see Figure 19). In these systems, the field is formed into flat basins separated by dikes or berms. Water is applied by allowing it to flow into the basin through a gate or valve until enough water to cover the soil to the required depth has entered the basin. Since the basin is level, the water spreads rapidly to all parts of the basin without any further action by the irrigator. These systems are used on many orchards in the Central Valley.

A recent development in level basin systems is their use on field crops. In this application, the field is formed into a few large basins. The labor costs of operating these large basins are low because a large area can be irrigated by opening a single gate.

Surface irrigation systems have gained a reputation for being antiquated and inefficient and inherently inferior to the more modern pressure systems. But this reputation is quite undeserved. It is true that in many cases, surface systems are designed or managed poorly

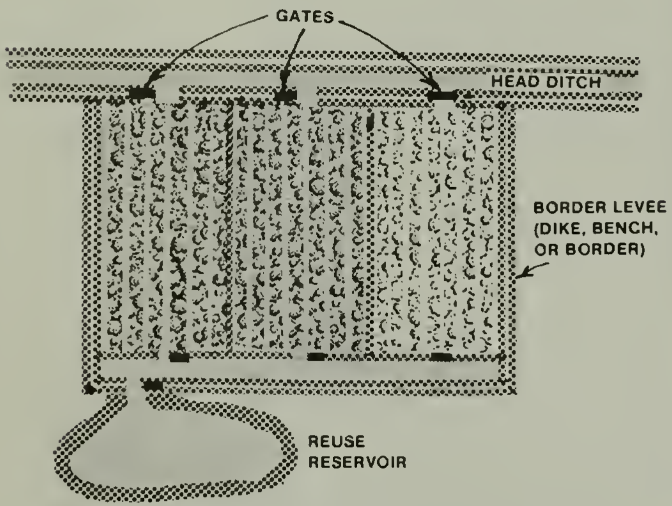
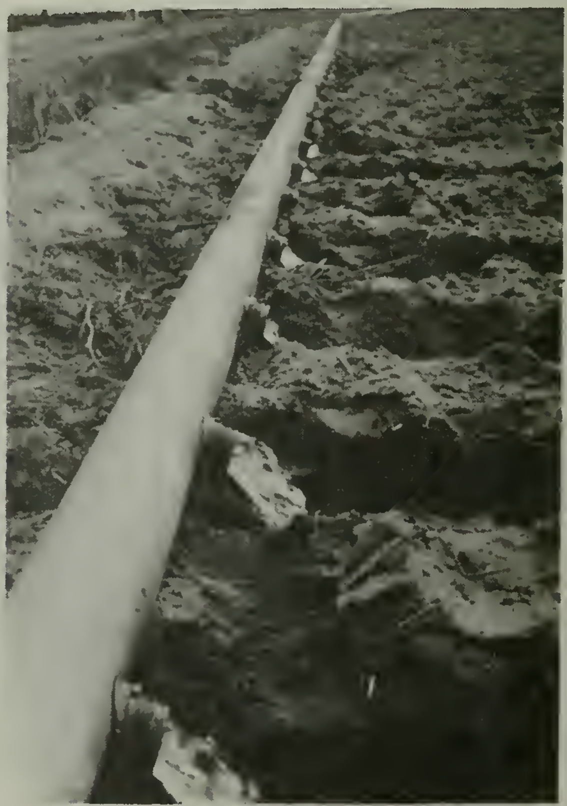


Figure 18. Water Application by Border-Strip Irrigation



Irrigation Using Gated Pipe

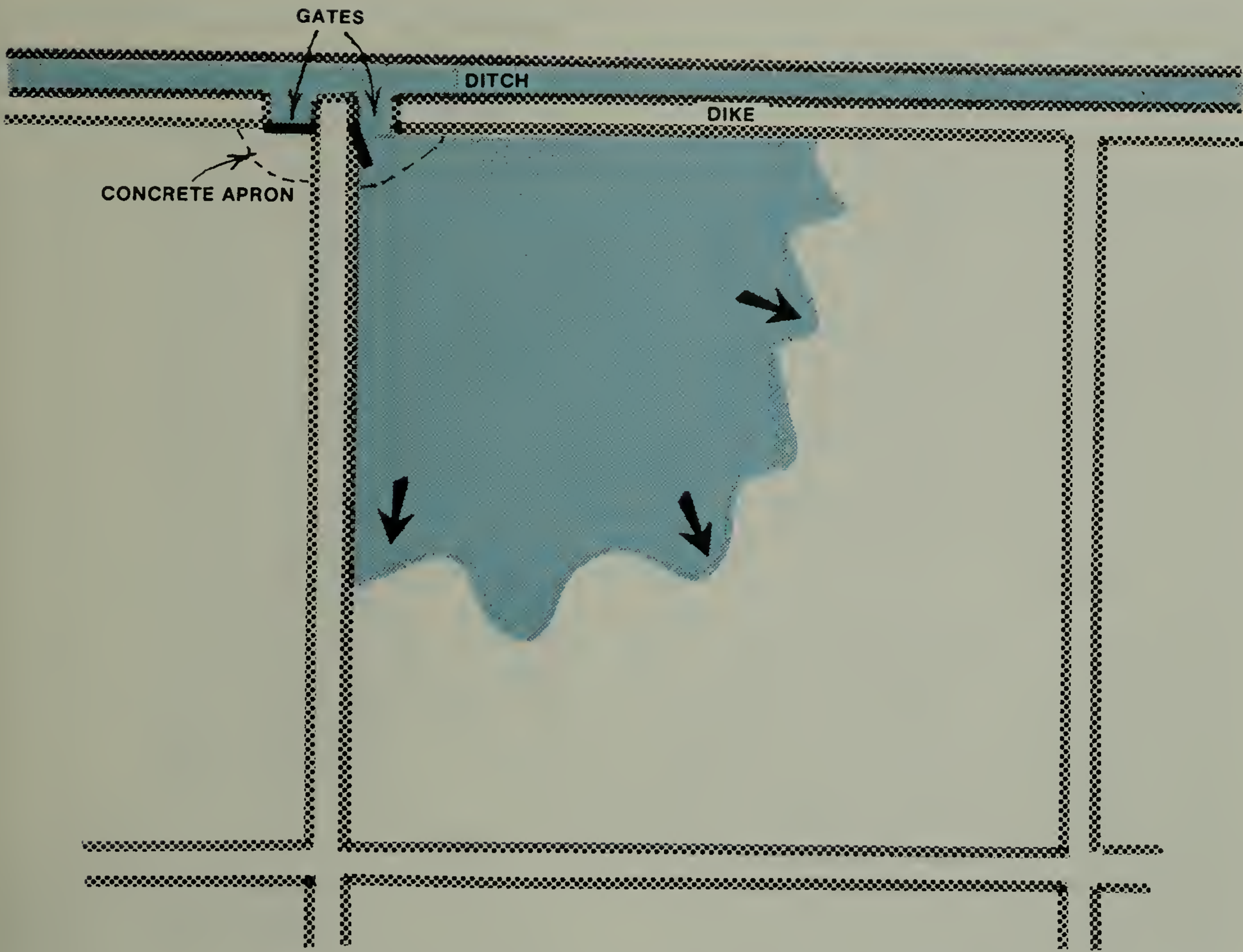


Figure 19. Water Application by Level-Basin Irrigation

with the result much of the water applied to the field goes to deep percolation or runs off as tailwater. But these systems are generally older systems, developed in areas with plentiful supplies of cheap surface water; in areas where water is scarce or expensive, surface systems are generally designed and managed carefully with the result that water losses are kept to a minimum. With careful design and management surface irrigation systems can perform just as well as pressure systems, although their management may be more difficult.

Irrigation of Graded Border Using Siphon Tubes

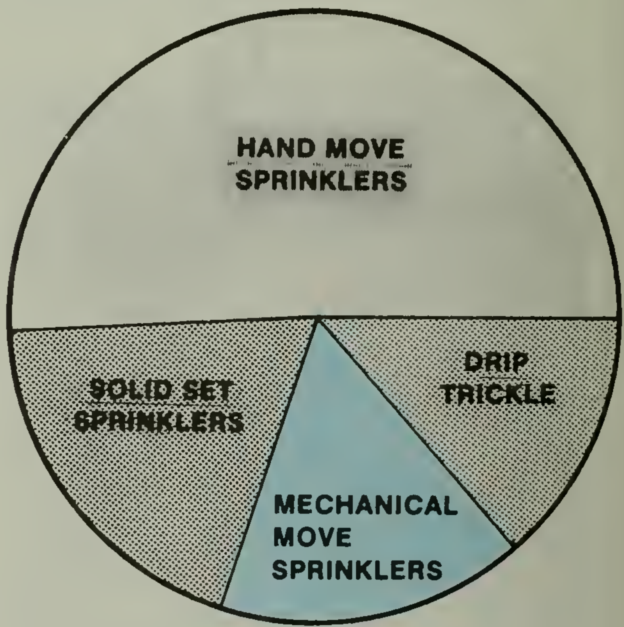
Pressure Systems

Pressure systems can be used successfully in situations where it is difficult to operate a surface system. Because pressure systems distribute water across the field by means of pipes rather than flow across the soil surface, they can be used on fields which slope too steeply to be irrigated successfully by surface irrigation or in areas where the ground is too uneven to be graded with the precision required for the successful operation of a surface system. Pressure systems are also used where the texture of the soil varies from place to place in the field, making it difficult to apply water evenly over the field by flow across the soil surface.

In many cases, pressure systems are used because they require less labor than surface systems. There is no need to carefully grade the land to a uniform slope because the water is distributed across the field by being pumped through pipes rather than being allowed to flow across the soil surface. When water is applied, the operator simply opens a valve and leaves the system on for the required time: there is no need to monitor the advance of water along the field or to adjust the flow into the furrows or strips. (Drip systems do require some monitoring in case the emitters become clogged.) The acreages irrigated by the different types of pressure systems are shown in Figure 20.

Pressure systems also offer advantages over surface systems where the terrain is uneven or highly sloping and may be more easily managed in some situations. However, where the terrain is fairly level surface systems may apply water as efficiently and require less energy for their management.

Sprinkler Systems. The most common type of pressure system is hand-moved sprinklers (see Figure 21). In these systems, water is conveyed across the field by means of a portable lateral connected to a permanent main running alongside the field. The main is equipped with a number of hydrants to which the lateral can be connected. The lateral is connected to the first hydrant and the water is turned on, irrigating a strip about 10 yards wide. The water is discharged by means of sprinkler heads mounted on risers. After water has been applied to the field for long enough for the soil to absorb the required amount of water, the lateral, which usually consists of 20-foot sections, is dismantled and carried along to the next hydrant to apply water to the next part of the field. Hand-moved systems are generally the cheapest pressure system, but these savings in capital costs are achieved at the expense of relatively high labor costs. Like all pressure systems, the energy cost of hand-moved sprinklers is high because the water must be pumped through the mains and laterals and reach the sprinkler heads at sufficient pressure to spray across the field.



(1,000's of Acres)

Hand Move Sprinklers	1,035
Solid Set Sprinklers	395
Mechanical Move Sprinklers	305
Drip/Trickle	260
Total Acres	2,040

Figure 20. Pressure Irrigation Systems

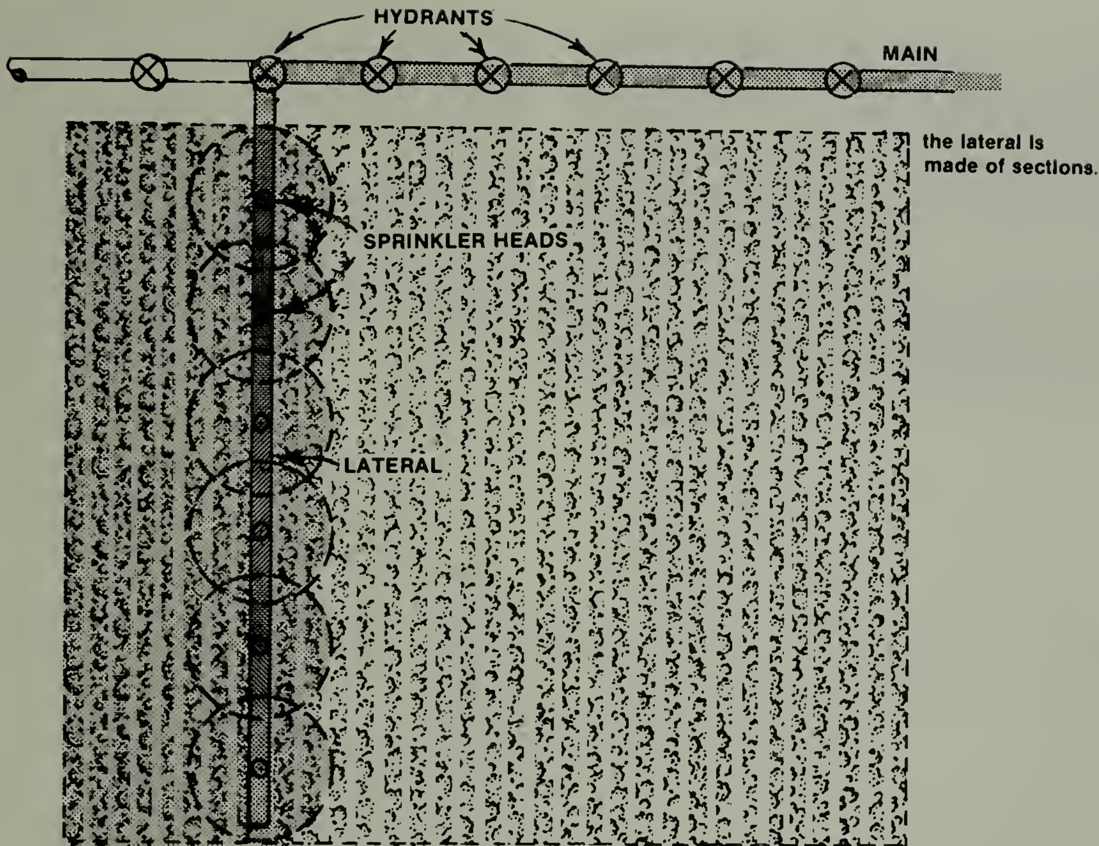
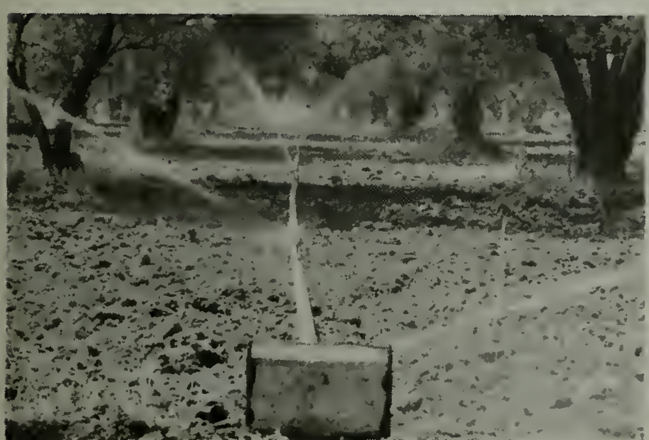


Figure 21. Operation of a Hand-Moved Sprinkler System

Some savings in labor costs can be achieved by using side-roll systems. In these systems, the lateral runs through the centers of a number of large wheels; these wheels allow the lateral to be pushed from hydrant to hydrant without being dismantled. Side-roll systems can be used on low-growing crops such as grains and alfalfa planted on regularly-shaped fields on relatively level land.


Hand-Moved Sprinkler System in Olive Orchard

Solid set systems are generally used in situations where a closer control over the application in water is coupled with a need to reduce labor cost, or potential damage to high value crops from moving sprinkler pipe can occur. When these systems are used, a lateral is connected to each hydrant and is left in place for the entire growing season. These systems are often used on shallow-rooted vegetable crops, where it may be necessary to apply small amounts of water to the crop every few days. The high capital cost of these systems is repaid by savings in labor costs and the increased yields of high-valued vegetable crops achieved as a result of the close control of water applications.

Permanent set systems are sometimes used in orchards and vineyards. In these systems, water is usually conveyed

Hand-Moved Sprinklers Operating in the San Joaquin Valley

across the field by means of underground submains rather than laterals laid across the ground. Risers convey the water to the surface where it is discharged by means of sprinkler heads. These systems are rarely used for vegetable crops because it is impractical to remove the risers every year to permit access by the machinery used to cultivate the field and sow the crop.

Some of the advantages of hand-moved and solid set systems are combined in traveling systems. In these systems, the lateral is mounted on wheeled towers, which move slowly across the field. One of the earlier types of traveling system is the center-pivot sprinkler (see Figure 22). In this system, one end of the lateral is connected to a well, which supplies the lateral with water. The lateral pivots about the well like the hand of a clock, applying water to a

Side-Roll Sprinkler Irrigation

circular area of land. The system is propelled by small motors driving the wheels in the towers supporting the lateral. The labor costs of operating this system are very low; the capital costs are much higher than the hand-moved systems, but lower than solid set systems. Center-pivot systems have a few problems resulting from the circular motion of the lateral. First, some of the grower's land is left unirrigated because the lateral does not reach the corners of the field. In California, where land is expensive, this is a serious disadvantage. Systems to apply water to the corners of the field have been developed but experience with them has not always been successful. Second, because the outer part of the lateral sweeps across the field faster than the part near the pivot, the outer sprinkler heads must discharge water much faster than those near the pivot. When the soil is heavy, the outer sprinkler heads may discharge water onto the field faster than the water can be absorbed by the soil; water will then collect at the lower parts of the field or run off the field, carrying away soil and fertilizer. Because of problems such as these, center-pivot systems have not become popular in California.

Linear-move systems have been developed in recent years to overcome some of the problems inherent in center-pivot sys-

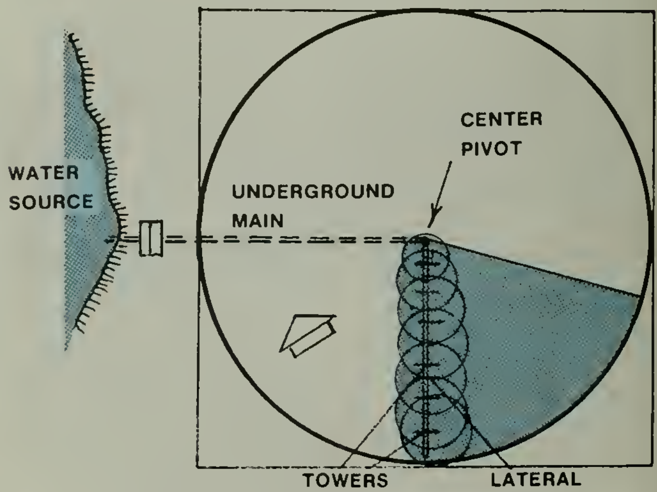


Figure 22. Water Application by Center-Pivot Systems

Center-Pivot Sprinkler Irrigation

tems. In these systems, the lateral picks up water from a ditch running alongside or down the center of the field and slowly moves from one end of the field to the other, applying water to a rectangular area of land (see Figure 23). Linear-move systems are still under development and as yet can be used on only relatively level fields. Nevertheless, experience with them has been very encouraging because they can apply water to a field with a high degree of uniformity.

Drip Systems. In drip systems, water is applied to the field by being allowed to drip from outlets called emitters rather than being sprayed through sprinkler heads. The water is distributed across the field to laterals by underground pipes similar to those used in permanent sprinkler systems. In this case the laterals are flexible lengths of hose

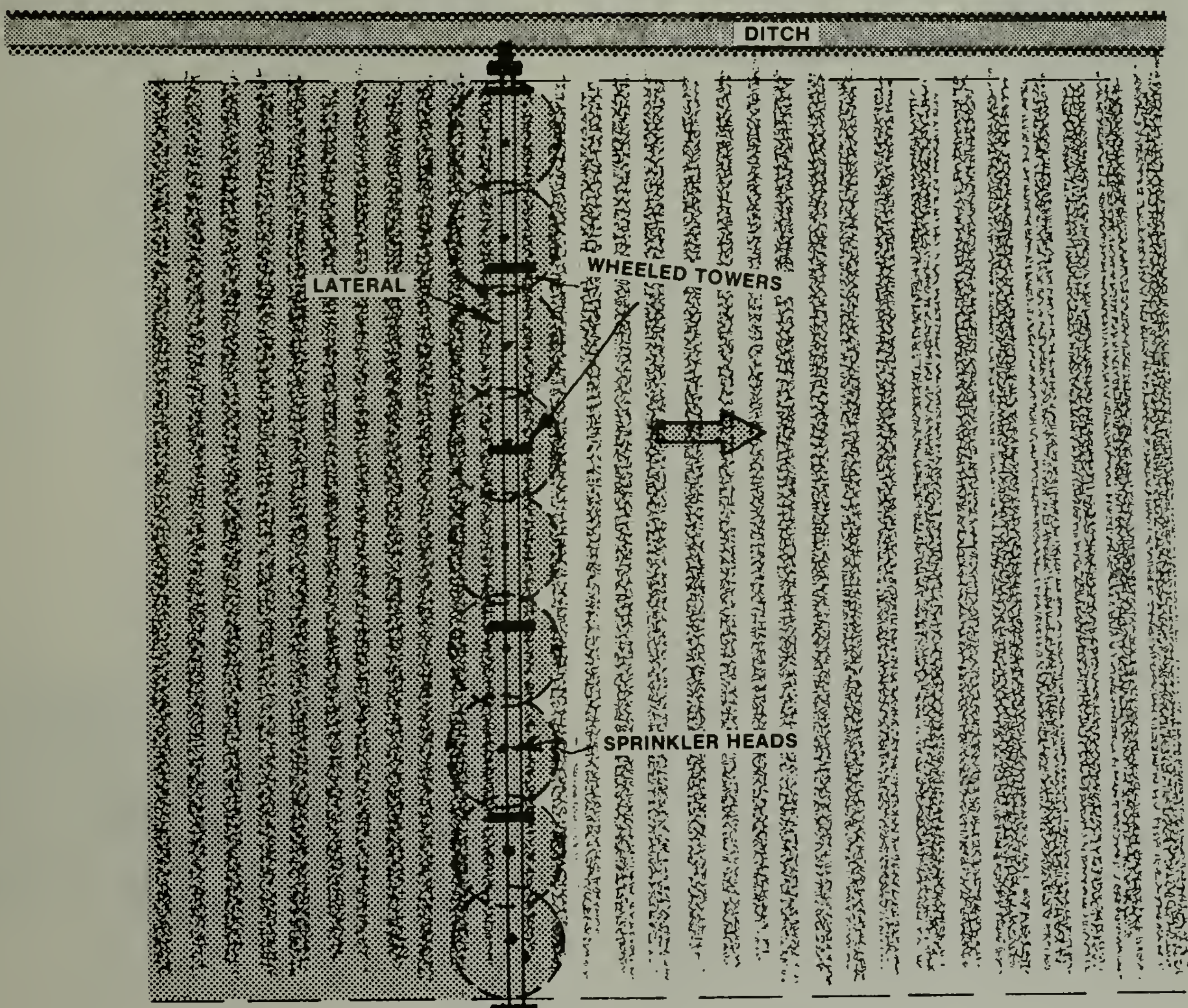


Figure 23. Water Application by Linear-Move Systems

Drip Irrigation in Young Vineyard

that convey the water to the plants. Water drips onto the soil through emitters installed along the laterals. These systems are very expensive, but allow a very close control over the way water is applied to the crop. Consequently, drip systems are used mostly on high-valued crops such as vines, fruit trees, bushberries, and vegetables. Drip systems can be used on land that slopes too steeply to be irrigated with other systems; most of the avocado acreage on hillsides in Southern California is irrigated with drip systems. Drip systems are becoming popular for growing high-valued crops in areas such as Southern California and the southern San Joaquin Valley where water is expensive.

Irrigation Management

The amount of water that a grower needs to apply to a field depends on the way in which the system is managed. Growers apply water in a way that will ensure that the soil in the part of the field getting the least water absorbs the correct amount of water. Thus, the amount of water that a grower needs to apply to a crop depends on how closely he controls the delivery of water to the field and on how evenly the soil absorbs water.

When furrow and border-strip systems are used, applications can be affected by the extent to which the grower controls the rate at which water flows into the field. For example, when water is applied by furrow irrigation, the water is turned into the furrows and allowed to flow toward the tail ditch. Because the water is absorbed by the soil as it flows along, it takes several hours for the water to advance to the low end of the field. During the irrigation, some flow of water through the end of the furrow is necessary to ensure that the depth of water in the lower part of the furrow is enough for the soil there to absorb water sufficiently; consequently, some flow of tailwater into the tail-ditch is unavoidable. This flow of tailwater can be reduced by cutting back the flow of water into the furrows when the water has advanced the full length of the field. The flow is reduced by adjusting the siphon tubes or partially closing the gates if gated pipe is being used. The flow of tailwater can be reduced to a minimum by monitoring the flow of tailwater and making further cutbacks later during the irrigation.

Monitoring the flow of tailwater and adjusting the rate of delivery of water to the furrows will result in a reduction in applications at the expense of

Construction of Turnout for Level Basin Irrigation (photo by U.S. Soil Conservation Service) some labor and management time. The motivation that a grower has to reduce applications in this way will depend on his particular circumstances. In deciding whether to monitor and adjust the flow during the irrigation, a grower will weigh the labor and management costs of this action against the value to him of the water saved. This value might be the savings in the grower's water costs or, in cases where the supply of water is limited, the value of using the water to irrigate other land. A grower will proceed with actions reducing his applications only in cases where the cost of these actions is less than the value to the grower of the water saved.

A grower's decision on whether to collect the tailwater and return it to the top of the field for reuse is based on similar reasoning. If tailwater is to be collected, some land has to be taken out of production to make room for a pond, the pond has to be excavated and pumps purchased and installed. A grower will proceed with such a project only if he has problems disposing of the tailwater or if the value of the water recovered exceeds the cost of installing and operating the system.

Uniformity of Application. In practice, it is virtually impossible to apply water to a field with complete uniformity. The texture of the soil almost always varies from place to place in a field, with the result that some parts of the field absorb water faster than others. A grower will have no choice but to apply water so that the part of the field absorbing water most slowly has time to absorb the required amount of water; other parts of the field will absorb too much water, and the excess will flow down as deep percolation.

When water is applied by surface irrigation, the absorption of water will always be uneven because the part of the field nearest the head ditch is wetted for longer than other parts of the field during the irrigation. For example, in furrow systems, it takes several hours for the water to advance from the head ditch to the tail ditch. Because the reach of the furrow near the head ditch has water in it longer than the reach of the furrow near the tail ditch, the soil in this part of the furrow will absorb more than the required amount of water. This excess water cannot be retained by the soil and will flow downward under gravity as deep percolation.

Although there is little a grower can do about variations in the texture of the soil in a field, there are a number of ways in which a grower can reduce the amount of excess water absorbed in the upper part of the field. The amount of excess water absorbed depends on how long the water takes to advance to the lower end of the field. The smaller the time of advance is, compared to the total length of time that the water is running down the furrow, the more even the application will be. There are several modifications that a grower can make to a system to reduce the advance time. One such modification would be to reduce the length of the furrow. Because water advances rapidly along the upper part of the furrow and then slows down as more and more water is absorbed by the soil, reducing the length of the furrow will markedly reduce the advance time. For example, if a quarter-mile-long field were divided into two eighth-mile-long fields, the advance time might be reduced by about two-thirds. Figure 24 shows how reducing the length of the field in this way will reduce the advance time of an irrigation and so reduce the excess water absorbed in the upper part of the field.

Dividing the field to reduce the length of the furrow will generally result in a reduction in water applications at the expense of additional capital expenditures and increased operating costs. The grower will have to construct an additional head ditch and tail ditch, provide a ditch to deliver the water to the second head ditch, and provide a drain to remove the tailwater from the

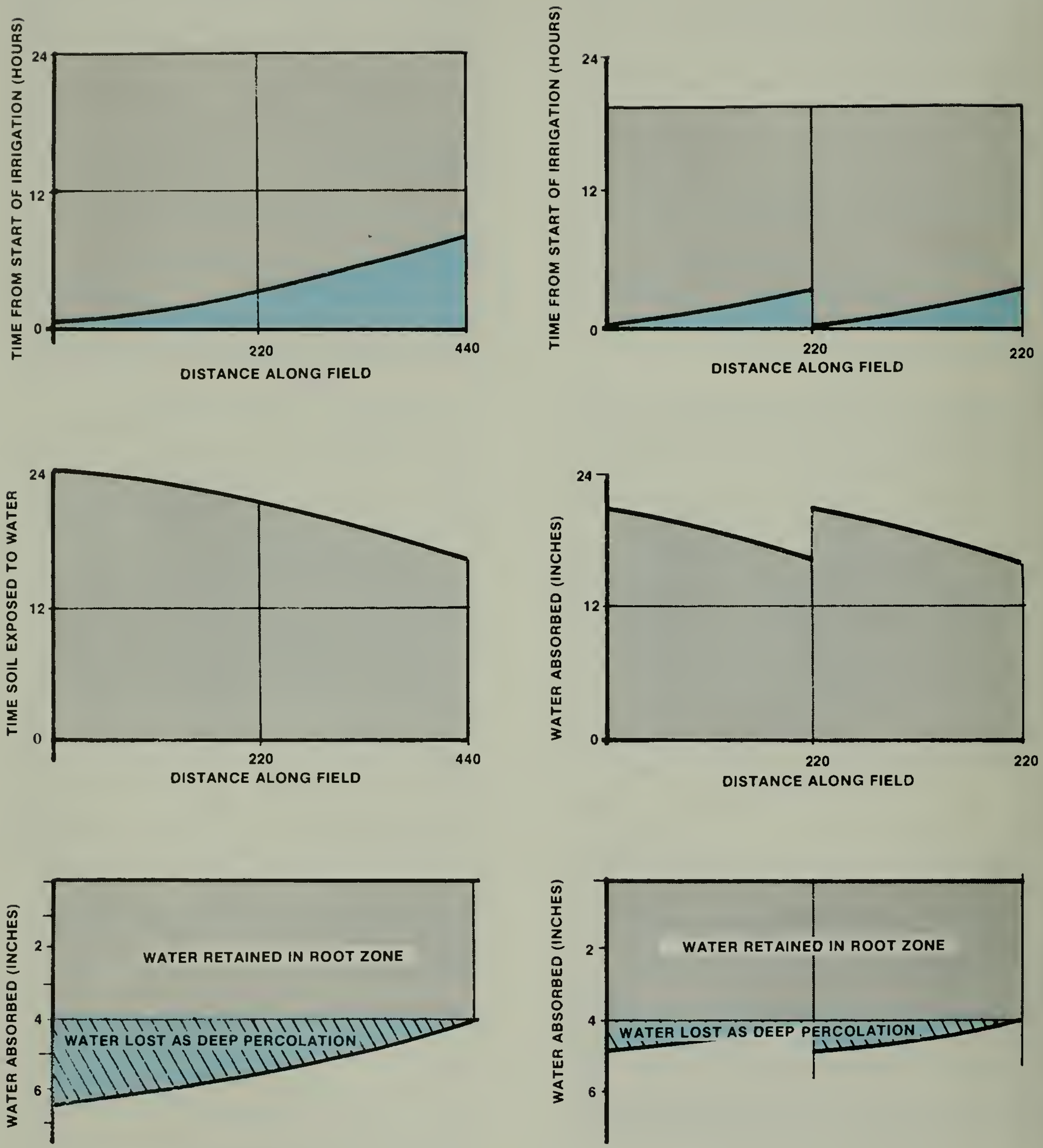


Figure 24. Effect of Reducing the Length of Furrow

second tail ditch. The grower's operating costs will be increased because the irrigator will have to place siphon tubes along two head ditches, doubling the labor costs of making an application of water. In addition, the cost of all of the operations needed to grow and harvest the crop will be increased somewhat because of the additional labor and machinery time needed to cultivate and harvest two small fields rather than one large field.

The benefits of reducing water applications will depend on the particular circumstances of the grower. The grower would achieve some savings in water costs; the extent of these savings would depend on the cost of the grower's water supplies. Because less fertilizer could be carried away by the flow of percolation water, the grower could also gain some savings in fertilizer costs. If the field were poorly drained, the reduced application would reduce the time for which the soil is waterlogged, increasing the yield and quality of the crop and reducing the chance of disease.

Before making a decision on whether to change his irrigation practice, a grower would carefully weigh the benefits of the change against the costs of modifying the irrigation system.

When sprinkler systems are used, there are generally some losses of water as deep percolation resulting from uneven applications of water. In addition to uneven sprinkler patterns due to wind, uneven distribution of water across a field is caused by the variation in pressure along the laterals. Because of the friction between the water flowing in the lateral and the inside of the lateral, the water pressure will fall along the lateral, often being 20 percent lower near the end of the lateral than near the main. Because of this fall in pressure, the sprinkler heads near the end of the lateral will discharge less water than those near the main. If the grower runs the sprinklers long enough to bring the soil at the far end of the field up to its full water-holding capacity, excess water will be applied to the near end of the field. This water will percolate below the root zone since it cannot be held by the soil.

There are several ways in which the distribution of water across the field can be made more uniform. One possible improvement would be for the grower to change to a larger pipe size, reducing the fall in pressure along the lateral. Another possibility would be to install pressure regulators at each sprinkler rise. Both of these improvements would increase the uniformity of the application, enabling lower applications of water. The grower could achieve savings in water and energy costs at the expense of the capital cost of making the improvements plus some investment in management time.

Variations of soil characteristics across the field will result in corresponding variations in moisture holding capacity within the root zone leading to greater deep percolation in some spots than in others. If the rate at which water is applied to the field is greater than the rate at which the soil can absorb the water, some water will flow acrosss the soil surface to the lower areas of the field. A solution to this problem would be to reduce the application rate so that all of the water sprayed onto the field could be absorbed as it fell on the soil surface. In fields of varying soils and infiltration rates, application rates should be reduced to below the lowest infiltration rate of the field. Reducing the application rate would, of course, mean that each application of water would take longer to complete. The grower might have to buy additional laterals because each lateral would be tied up for a longer time on each set. It is possible that the longer application time would be inconvenient for the grower to work into his operation, resulting in increased labor and management costs. Before deciding whether to reduce his application rate, a grower would carefully consider whether labor, management, and capital costs of the change would be repaid by savings in energy and water costs.

Irrigation Scheduling. The amount of water that a grower applies to a crop over the course of the growing season depends on the amount of water applied in each irrigation and how many times the crop is irrigated. In order to keep labor and management costs to a minimum, a grower makes as few irrigations as possible, each time bringing the soil in the field up to its full water-holding capacity. Thus, the grower should generally attempt to apply water so that the part of the field getting the least water absorbs just enough to replace the water consumed by the crop since the previous irrigation and provide for leaching minerals from the root zone, if necessary. If possible, the grower should delay irrigation until just before the soil moisture has been depleted to the point where it will harm the crop. Matching applications closely to the rate at which water is removed from the soil by the crop will mean that the total amount applied can be reduced, because less excess water will be absorbed by the soil and move below the rooting zone as deep percolation.

Scheduling irrigations in this way is not an easy matter. The rate at which a crop consumes water varies over the growing season on account of both the weather and the stage of growth of the plants. The extent to which the soil moisture can be depleted safely also varies according to the depth to which the plants' roots have grown and the tolerance of the plants to stress at a particular stage of growth. Thus, the amounts of water that a grower needs to apply and the intervals at which he needs to irrigate vary considerably over the course of the growing season. Matching irrigations to the needs of the crop requires the investment of some management time and possibly the retaining of an irrigation consultant.

The way in which a grower gets his water may prevent him from scheduling irrigations to match the needs of his crop. Many growers in the State get their water through a system of canals operated by an irrigation district of some kind. These districts deliver water to growers according to a fixed delivery schedule because it would be uneconomic to build the canals large enough to provide all growers in a district with water at the same time. In some cases, these delivery schedules do not allow a grower to apply water exactly as he would like to. For example, a district might operate by allowing growers turns to divert water from the canals, each time allowing a grower to divert water for 24, 36, or 48 hours. A grower supplied with water in this way would not be able to schedule his irrigations to match the rate at which water was used by the crop.

Growers of perishable crops in particular need to guard against sudden hot, low humidity weather conditions which might deplete soil moisture before water can be applied.

Although scheduling irrigations to match the needs of the crop can mean that less water is applied and fewer irrigations are made, many growers irrigate according to a fixed schedule because of inflexible delivery from their water suppliers or because they feel that the additional management costs from scheduling would outweigh any savings in water and labor costs.

Effects of Changes in Irrigation Practices

Improving irrigation practices reduces tailwater and deep percolation. This may have a direct effect on the farmer's operations and off-site effects on others. The primary focus of this section is on the on-farm and off-farm effects of tailwater and deep percolation.

Some of the water pumped from wells or

diverted from rivers becomes tailwater as a result of irrigation practices. Most tailwater is eventually collected in drains or canals and returned to a river for downstream use. By increasing irrigation efficiency and reducing the amount of water diverted from rivers, more water can become available for other instream uses such as maintaining fisheries between the point of diversion and the point where the return flow is discharged into the river.

For example, an irrigation district may divert water from the Sacramento River. Irrigation water is used and reused on crops such as rice and finally discharged into a drain. The drain then empties back into the Sacramento River for downstream use.

There can be a water quality decline of various degrees, dependent on local conditions and practices, associated with tailwater reuse. This water may pick up dissolved and suspended solids and agricultural chemicals (fertilizers and pesticides). Reducing tailwater means downstream water users could receive better quality water. Furthermore, reducing excessive pumping of water from wells or tailwater sumps saves energy and pumping costs.

In many areas tailwater helps maintain wetlands. These wetlands provide habitat and food for many species of birds and animals. Successful agricultural water conservation could significantly reduce the amount of tailwater flowing into wetlands. For example, state, federal and privately owned wetlands in California's Sacramento Valley rely heavily on supplies of rice tailwater. Using this tailwater is an inexpensive way to maintain these wetlands which are important to wintering birds and other wildlife.

Wetlands in the San Joaquin Valley also depend on tailwater. For example, the area surrounding Los Banos supports about 70,000 acres of public and private wetlands. Over half of the 19,000 acre-feet of water flowing into these wetlands is tailwater. Tailwater completely supplies the Kesterson and Volta Wildlife areas. Tailwater supplies half of the water used in the San Luis National Wildlife Refuge. Furthermore, the U.S. Fish and Wildlife Service proposes to use tailwater in the Kern National Wildlife Refuge.

Deep percolation can be considered beneficial when it occurs from overirrigation or poor distribution uniformity if it recharges the groundwater, provided that the groundwater quality is such that it can be reused, and it can be extracted.

Where deep percolation recharges groundwater it must be pumped to the surface for reuse. Therefore, additional pumping requires energy and costs farmers money. Even though deep percolation may recharge an aquifer, the grower who overirrigates may not always directly benefit from the aquifer he is recharging.

Deep percolation can degrade groundwater quality. When irrigation water infiltrates into the soil it carries fertilizers and other agricultural chemicals with it. Through evapotranspiration,

Concrete Lining of Distribution Ditches Reduces Deep Percolation (photo by U.S. Soil Conservation Service) plants remove virtually pure water from soil. Therefore, irrigating concentrates salts in the soil. In order to keep the crop root-zone from becoming too saline for plant growth, extra water is usually applied to leach these salts below the crop root-zone. This water not only picks up these concentrated salts, but it also picks up salts that occur naturally in soils. The quality of the water that eventually reaches the groundwater may have been reduced significantly. Furthermore, deep percolation does not always recharge groundwater tables. The downward movement of water in soil may be stopped if it reaches a clay or some other type of nearly impervious layer between the soil surface and bedrock. These layers may not completely stop the downward water movement, but they may slow it to a point where water "builds up".

When the water build-up is close to the soil surface it is called a perched water table. Perched water tables can result in drainage problems and if the perched water is saline, cause soil salinity to rise to undesirable levels. The extent of the perched water table depends on the area of the impermeable layer.

Where possible, one solution is to break up the restricting layer and allow the water to continue percolating downward. This process, called deep ripping, only works for certain, relatively shallow restricting layers. Another solution is to install drains to remove the excess water. Improved irrigation water management practices can help reduce deep percolation which in turn can help reduce drainage problems.

Deep percolation also won't recharge groundwater if it is intercepted by moisture deficient soils. Moisture deficient soils are extremely dry. They are an unusual phenomenon found along the West Side of the San Joaquin Valley. Any water entering moisture deficient soils is immediately attracted to and held tightly by the soil particles. As a result, any deep percolation entering moisture deficient soil areas can be considered lost because it does not recharge the groundwater and cannot be reused.

In most situations it is in a farmers economic interest to manage water efficiently on-farm so as to minimize tailwater and deep percolation. However, such actions do not always represent a water supply savings and can have both positive and negative effects off the farm.

Water Conservation Opportunities in the Imperial Valley

One area of the State where reductions in applied water on farm do represent water supply savings is in the Imperial Valley. Almost all of the tailwater and water collected in tile drains eventually reaches the Salton Sea and is unavailable for reuse. The water conservation potential in the Imperial Valley is important to the State because of changes in Colorado River diversions that will occur in the future.

Presently, California agencies are entitled to divert all of the Colorado River water that they can put to beneficial use. However, when the Central Arizona Project commences deliveries, now scheduled for late 1985, there will be a radical change in California's ability to take needed Colorado River water. At that time, California's uses will be restricted to the State's basic apportionment of 4.4 million acre-feet per year under "normal" conditions.

The California Seven-Party Agreement, which sets forth the priorities to Colorado River Water of each California agency, reserves the first three priorities, totaling 3,850,000 acre-feet per year, to California's agricultural users: the Palo Verde Irrigation District, the California portion of the Yuma Project, Imperial Irrigation District and Coachella Valley Water District.

Thus, the Metropolitan Water District of Southern California (MWD), which has been able to divert up to 1,212,000 acre-feet/year under the fourth and fifth priorities of the Seven-Party Agreement, will be limited to a maximum diversion of 550,000 acre-feet/year when California's use is restricted. Small miscellaneous rights and existing lower Colorado River Indian Tribes' rights not included in the Seven-Party Agreement but having a higher priority than MWD could reduce MWD's entitlement to slightly less than 500,000 acre-feet/year. Depending on the outcome of a lawsuit, now pending in Federal district court regarding disputed Indian Reservation boundary lands, MWD's entitlement could be further reduced.

The Imperial Irrigation District (IID) covers almost 1.1 million acres in Imperial County. About 500,000 acres of District lands are presently irrigated. Principal crops include alfalfa, wheat, cotton, and lettuce.

IID's only source of water is the Colorado River, from which water is transported through the 80-mile-long All-American Canal to IID's distribution system. Agricultural drainage water from the District is discharged to the Salton Sea, a saline body of water not usable for urban or agricultural use without desalting.

New facilities introduced by IID over the past several years have increased its irrigation efficiency by reducing the amount of water lost to seepage and spills from canals and laterals and by reducing the amount of tailwater within the District. These measures include concrete lining of laterals, the construction of four regulatory reservoirs on the principal canals within IID, and the establishment of specal operational rules that penalize farmers for exceeding certain tailwater limits. The lining of laterals has principally been on a cost-sharing basis with farmers whose lands adjoined a section to be lined and has not included the district's main canals.

Even though IID's current operational practices result in an irrigation efficiency that compares favorably with other districts, the efficiency could be improved and significant amounts of water saved if substantial investments were made to upgrade components of its systems. The amount of water that potentially can be saved is in excess of IID's foreseeable future needs.

During 1980 and 1981, the Department of Water Resources conducted a reconnaisance level investigation of the use of water in IID and identified potential water conservation measures. The U.S. Bureau of Reclamation (USBR) also initiated in 1980 an appraisal level investigation, completed in 1983, to study water conservation opportunities within IID. Based on this investigation, the USBR also concluded that water conservation opportunities within the District do exist. Consequently, the USBR has proposed to follow its appraisal level investigation with a more detailed feasibility study, to commence in fiscal year 1985, to more accurately identify the quantity of water that could be saved and the associated costs. In addition, the USBR has proposed a feasibility study, to be started in

Furrow Irrigation in the Imperial Valley

1984, for lining a 30-mile reach of the All-American Canal.

The USBR appraisal level investigation identified water conservation opportunities within IID of about 350,000 acre-feet/year through (1) canal lining and system automation, (2) construction of regulating reservoirs and spill interceptor systems, and (3) implementation of on-farm water management programs. The USBR's preliminary estimate of the capital costs of these water conservation measures is about $131 million. The USBR estimated that another 70,000 acre-feet/year could be saved by lining the All-American Canal from Pilot Knob to the District's East Highline Canal at a capital cost of about $130 million.

While the bulk of these water conservation measures is not currently economically justified for IID, they are likely to be justified for MWD, the holder of subordinate priorities to the use of Colorado River water. Financial support by MWD of IID's water conservation program should provide significant benefits to IID.

MWD would directly benefit from the water conservation measures if the supplies could be developed relatively quickly and would be less costly than other alternative supplies.

In addition to the question of whether or not water conserved by IID would be available for use by MWD, there are a number of issues of a factual-technical and an institutional-community nature that would have to be resolved before an IID water conservation program funded by MWD could be implemented.

Alfalfa in the Coachella Valley

The major factual problem is the determination of the actual reduction in water use due to a water conservation measure. It is difficult to measure with precision the water saved by those measures that would be designed to eliminate seepage. These measures include the relocation and construction of a lined section of the All-American Canal, and the lining of sections of the District's canals and laterals. However, by carefully conducting appropriate tests and analyses, it should be possible to obtain an estimate of seepage reduction that would be acceptable to all parties as the amount of water saved to be credited to specific measures.

The amounts of water conserved that would result from those measures that would reduce canal and lateral spills and on-farm tailwater volumes are much more difficult to verify. These measures (regulating reservoirs and automated equipment) must be carefully operated in order for the present spills to be reduced. In addition, the amount of spills reduction can vary with changes in system operations making it even harder to define actual savings. Studies of these water conservation measures are complex, but it should be possible to conduct such studies so as to arrive at mutually-acceptable estimates of water savings.

While there are significant benefits that would be received by all agencies participating in a water conservation program within IID, it is nevertheless a very sensitive issue. Community leaders in Imperial Valley have expressed fears that water rights that may be needed in the future could be lost. Further, MWD needs reasonable assurance that it will receive the water conserved through its investment and, as the agency in the middle, Coachella Valley Water District, which shares third party rights with IID and Palo Verde Irrigation District mesa lands, needs to know that its interests will be fully protected.

APPENDIX A. ADVANCES IN IRRIGATION

Surface Systems

Surface irrigation methods will continue to change as new technology becomes available. The need for more efficient irrigation with low labor costs and energy consumption will result in continual changes in irrigation methods. Water, energy and some environmental conservation considerations will require irrigation systems that operate with little or no surface runoff from the farm and minimize deep percolation below the root zone.

Automation

With the current equipment available to irrigators, some surface methods are relatively labor intensive. To obtain high efficiencies, the irrigator must be in the field most of the time checking the system, changing the water, revising the sets, resetting siphon tubes, changing dams, and starting and stopping pumps. Therefore, to preserve the energy benefits of surface irrigation, one option is to automate the system. What are the criteria that will make an automatic surface irrigation system acceptable to users?

1. It must give the irrigator positive control over available water.

2. It must offer flexibility in timing of applications to adjust for variable field conditions, and flexibility in capacity to meet individual furrow and total field requirements.

3. It must be reliable and operate without excessive clogging, breakdown, or malfunction with a minimum of maintenance.

4. It must be labor saving.

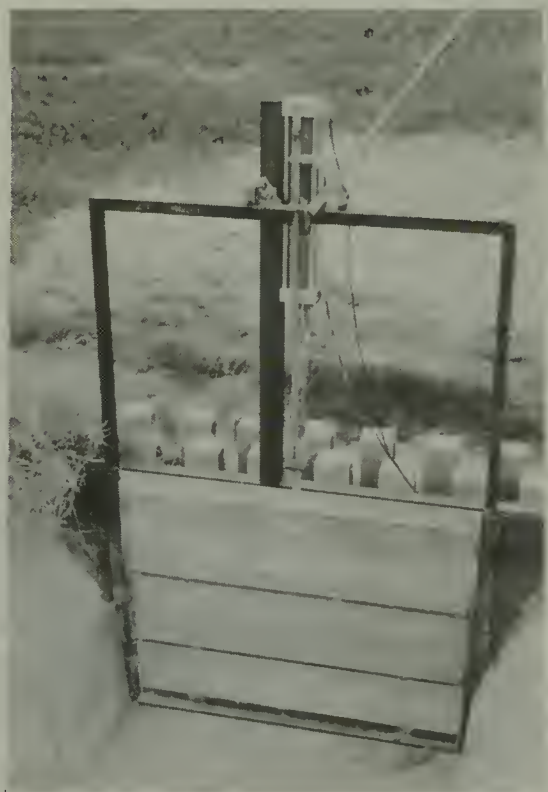
5. It must be available as a prepackaged unit, or a potential user must be able to buy a pre-engineered system (or the component parts).

6. It must have cutback capability to eliminate excessive runoff.

7. It must be cost effective.

Rising labor and production costs and limited water supplies are the forces driving growers to make irrigation more efficient. Because less energy is required for surface systems than for pressurized systems, increased emphasis is being placed on automating surface systems.

Traditional sloped furrow irrigation



Automated Turnout Gate

systems are being automated with emphasis on increased infiltration uniformity and reduced runoff. In such systems, streams are introduced to the furrow at or near the maximum nonerosive flow rate. When the water nears the far end of the furrow, the stream size is reduced and only small amounts of surface runoff occur. Manual cutback systems have not been popular because of the high labor required.

Laser Leveling

The technology of laser leveling has made it possible for growers to more easily and precisely smooth the slope of their existing surface irrigation systems or to dead-level their fields to make a level-basin irrigation system. Laser leveling investments may conserve water by improving application efficiencies, i.e., reducing runoff and deep percolation. Laser leveling may also increase farm profits by reducing applied water use and increasing crop yields through better water distribution over the field.

The hardware for a laser leveling system consists of a rotating command post from which the laser beam is emitted, generating a light plane on the level or at a predetermined grade. A receiver is mounted on a mast attached to a scraper. The signal keeps the scraper blade on the desired grade by operating hydraulic control valves automatically. The results obtained have been within plus or minus five hundredths (.05) of a foot. This is a greater accuracy than can be obtained with traditional land leveling methods.

Growers with expensive irrigation water will receive the greatest benefit from laser leveling. The amount of applied water reductions depend on the crop's ET demand and the change in irrigation field efficiency after laser leveling. Laser grading and dead-leveling can create substantial improvements in application efficiency. Specific farm efficiency improvements will depend on the initial field efficiency, the existing irrigation system, and the soil texture.

Cablegation

This is a newly developed means to automate water delivery to both graded border and furrow irrigated fields. Once set into operation, cablegation requires no labor to change water from furrow to furrow or from one border strip to the next.

At the head of the field, a carefully graded pipeline is placed. Holes are

Tractor and Scraper Leveling Land Using Laser Beam Technology

Rotating Command Post

drilled in the pipeline corresponding to the furrow spacing, or larger and/or more holes are drilled for border sys tems. Within the pipeline is a bowl-shaped polyethylene plug attached to a reel by a cable. As water enters the pipeline during an irrigation, the plug stops the forward motion of the water down the pipeline. Pressure mounts at the plug and water is forced out of the pipe into the field.

A timing mechanism, either powered by electricity or the flowing water in the pipeline, controls the rate at which the reel unwinds or feeds out the cable. As the plug moves down the pipeline pushed by the force of the water, each hole gets an initially high rate of flow that gradually diminishes to zero. Controlling the speed at which the plug moves down the pipeline allows areas to be irrigated for desired lengths of time.

Cablegation may have its greatest benefits on graded border systems in highly permeable soils. On these soils, border systems can be more efficient than furrow systems, but require additional labor to move water from strip to strip. Automatic sequential delivery of water from strip to strip can make graded borders more practical than furrows with these soils.

SurgeFlow

Surge flow is a technique whereby water is delivered intermittently to the furrows or borders used for surface irrigation. The on-off cycling of the flow for specific time periods produces surges during the "on" period, while also influencing the soil intake rate during the "off" period. This results in an increase in the distance a given volume of water will travel down a furrow. The reason for the reduction in infiltration rate with this sytem is still not completely understood. The results of tests from Utah State University revealed that 140 gallons of continuously flowing water traveled 260 feet down a furrow in 100 minutes. With surge flow, the same amount of water traveled 600 feet, and the infiltration into the soil was more even along the length of the furrow.

By doubling or trebling the distance a given volume of water travels along the furrow, irrigators can overcome some of the inherent imperfections of present practices, such as excessive deep percolation of water at the head of the furrow to achieve adequate irrigation of the root zone at the other end. The difference in intake opportunity time between the head of the furrow and the lower end is reduced, resulting in a more uniform distribution of water. Excessive runoff at the lower end may even be eliminated by adjusting the ratio of the off-on time. Design criteria for different soils, slopes and crops remain to be determined and operational field models have yet to be manufactured.

Design

The Soil Conservation Service (SCS) has developed a procedure of computerized surface irrigation analysis. Their concepts and procedures are still being reviewed and revised. The procedures contained in the Irrigation Method Analysis Program are, in general, procedures given in the Surface Irrigation Section of the SCS National Engineering Handbook (1974, 1979), which covers border and furrow irrigation. The equations are a combination of theoretical and empirical developments generally applicable in irrigated areas of the western United States.

If a surface system is properly designed and managed, high efficiencies can be attained. Efficiencies in excess of 85 percent are now being obtained by careful preparation of the soil and proper engineering design. Deep percolation is controlled by adequately matching advance time, application time, and length of run. Runoff leaving the field can be essentially eliminated by tailwater recovery systems and reuse.

Other hardware advances in surface irrigation include pneumatically controlled valves for automation of surface systems and portable float valves. These float valves can be moved in the field to regulate pressures for gated pipe systems, thus increasing the uniformity of application and, therefore, irrigation efficiency.

Pressure Systems

Drip irrigation methods provide better water control in some cases with a modest increase in energy per unit of water but are currently economical on only the highest valued crops. The primary alternative to surface irrigation for field crops is a sprinkler system. Properly designed and operated, a sprinkler system can be efficient, but at substantial energy costs. The advent of rapidly increasing energy costs and uncertain water supplies has resulted in the development of low pressure sprinklers that can retain efficiency, while reducing the energy requirement to a fraction of that required by sprinklers a few years ago.

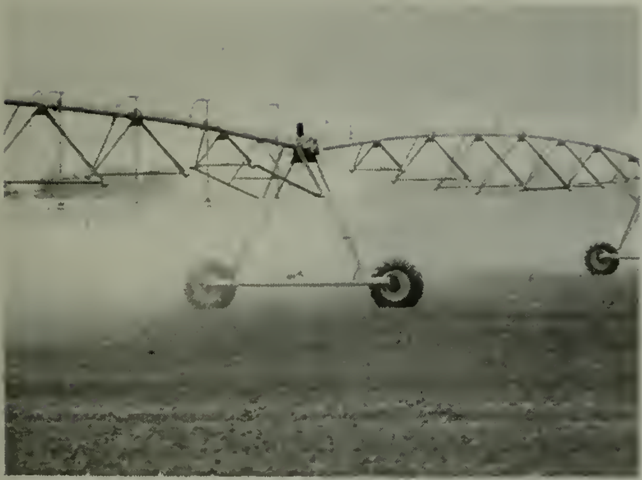
On many farms, the surface-irrigation techniques cannot be used due to variability in the soil or uneven topography. This considerable acreage can be efficiently irrigated by trickle or sprinkler systems only.

Linear (Lateral) Move Sprinkling Systems

The reduced energy requirement of modern sprinklers is a result of reducing operating pressure and a redesign of the heads and nozzles to maintain proper droplet size and pattern uniformity. When low pressure heads are combined with a continuously moving lateral, there are a number of additional advantages to the system: (1) the heads are closely spaced along the pipeline to increase uniformity; (2) the constant, consistent motion of the system provides excellent application uniformity in the direction of travel; and (3) the application rate of the system can be easily varied to suit the crop requirement by changing the travel speed of the machine. This factor alone is of considerable value in improving irrigation efficiency.

Surface irrigation methods can seldom be used to efficiently apply a light irrigation. The lateral-move sprinkler can be equipped with booms or drop tubes that allow the sprinkler to be just above the crop canopy. Placing the head closer to the ground reduces the time the water is in the air and therefore reduces evaporation and wind drift.

In the late 1970's, several manufacturers of center pivot sprinklers developed linear move sprinklers for areas where pivots were not suitable. In 1977, the first of these machines was used in the Bakersfield area and the numbers have grown to between 50 and 100 since then. Farming companys in this area have rea-



Lateral Move Sprinkler System with Low-Pressure Sprinklers on Booms

lized considerable reduction in energy and applied water when compared to conventional sprinklers. Their first unit was designed to carry 3200 gpm to irrigate 320 acres. The most recent machine delivered to them needs only 2200 gpm to irrigate the same 320 acres.

A typical linear-move system is one-half mile wide and runs a 1-mile course. Normally, water is supplied from a lined ditch in the center of the field. However, automated linear lines have recently been designed with two computer-controlled "grabber tractors" per unit, which automatically couple and uncouple to a series of valves spaced 50 feet apart on a buried mainline running down the center of the field. In this manner, one "grabber" seeks out and couples to the next valve in line, while the first feeds water into the system, and vice versa, so that the machine can provide continuous irrigation with no interruption in water pressure or machine movement.

The system generates its own electrical energy for movement from a diesel generator, which uses about a gallon of fuel per hour. The generator puts out 480 volts to supply energy for the electric motors on the "grabber tractors" and for the 1-horsepower electric-drive motors on each of the towers. The computerized control center for the system keeps it running in a straight line in the field (by following buried cables), provides power for the tower motors, controls unit speed and water flow rates, and controls the movement of the valve grabber tractors. Replaceable computer cores allow one operator to change the program of the system, for different crop water needs, in minutes. Water application rates of 0.1 inch to 2 inches per set can be adjusted.

For high-wind conditions, low pressure sprinkler heads (20 pounds per square inch) are mounted on spray booms just 10 feet apart, so that every inch of the field is covered with a fine mist, and wind skips are avoided. With the small droplet size applied, soil crusting has been completely eliminated.

Another advantage is the low labor requirement; also, fertilizer can be applied at the booster pumps. The closed water mainline can be an important factor in an area of frequent strong winds, as dust and tumbleweeds can produce a constant maintenance problem. Initial cost, however, is high. A typical linear-move system currently costs about $170,000.

The uniformity and application precision have allowed a considerable reduction in

Lateral Move Sprinkler System and Lined Supply Ditch

Lateral Move Irrigation System in Cotton

applied water to produce a crop. Both the manufacturers and users of the equipment have recognized the need for further research and development with the Linear Move Systems to realize its full potential for California agriculture.

The most important part of the documentation of the efficiency of the LMS is measurement of the response of a crop grown under it. The precise application of water is vital for reducing the field water requirement to a minimum. Moreover, spraying a relatively narrow strip pattern that moves rapidly and frequently over the field affects the growth of crops in several ways. The light, frequent applications are more similar to a trickle irrigation system than the infrequent, longer irrigations typical of surface irrigation and traditional sprinklers.

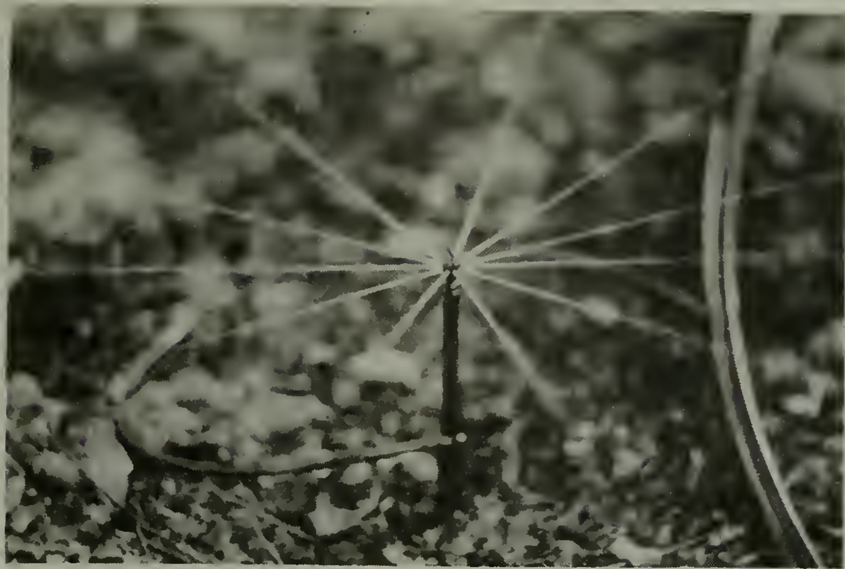
There is evidence of favorable crop response to this schedule due to reduced insect problems and improved pollination in the case of cotton. Daily sprinkling of the foliage will wash insect eggs and small insects off and prevent damage, while reducing the need for pesticide application. The increase in humidity produced by the frequent irrigation may also have a beneficial effect on the bloom set of cotton.

The systems have been successfully used on alfalfa, small grains, field and truck crops, and vineyards. Ground clearance of standard machines is 10 feet. Use of these machines on dwarf varieties of both deciduous and subtropical tress appears to be feasible and is now being investigated by at least two manufacturers. The machines can also be operated over irregular land surfaces. Limitations are about 12-percent slope in direction of travel and 3-percent side slope. A principal limitation is the requirement for long, rectangular fields free of obstructions. The ideal field size is 1-mile long by 0.5-mile wide.

The advantages of the linear move systems may be useful for more than just improvement of efficiency of traditional cultural practices. The elimination of the irrigation furrow could allow a higher plant population, fewer trips through the field with cultivation equipment, and better water efficiency by providing a full crop canopy more quickly.

Other Innovations

Low-Volume Sprinklers. Another advancement in pressurized irrigation is the low-volume localized sprinklers now available. Sprayers, spitters, foggers and minisprinklers are available, with flow rates from 2 to 60 gallons per hour at pressures ranging from 5 to 30 psi and wetted diameters from 3 to 30 feet. Increasing the flow capacity of a system, and using low-volume sprinklers rather than drip emitters, can overcome the disadvantages of a drip system. The



Low-Volume Minisprinkler Irrigation

higher flow rate per unit area allows the crop to be irrigated in a shorter time, reducing the need for a continuous water supply. This will also wet a larger volume of the root zone and no multiple zones of salt accumulation will occur as found at the edges of the "onion" zones around drip emitters.

Flow rates can be monitored visually and much more quickly than is possible with most drip installations, and because of the larger orifices, clogging is less of a problem. The flow rates of these devices fill the gap between drippers and conventional sprinklers. The advantages over sprinklers in tree and vine crops are that first, the foliage and trunks do not get sprayed, and second the areas between the rows remain dry.

The low application rates minimize the risk of runoff, and the small droplet size has minimal effect on the soil surface. There are many distribution patterns ranging from 40° up to 360° and foggers. Wetted areas vary from 5 to 300 square feet. With this style of irrigation system, the supply tubing can be buried, on the soil surface, or suspended above ground, depending on the cultural practices being used. As with drip and sprinkler irrigation, chemical injection is easily accomplished for a variety of crop needs. These systems are also easily automated.

<u>Computerized Systems</u>. Trends in pressure irrigation are towards computerization. The detailed examination of water

Computerized Controller for
Automated Irrigation Management

needs and the electronic processing of data will be combined in the future to ensure that water is utilized to the maximum benefit and that labor dependence is reduced to a minimum. These practices are currently somewhat common in Israel.

The computerized irrigation control system attends to all vital irrigation functions on a real-time basis. Environmental conditions (such as wind speed, air temperature, soil moisture, rainfall, etc.) and flow rates, water quantity, and water pressure, can be continuously (24 hours a day) monitored before, during, and after every irrigation cycle. Control of insecticides, fertilizer injection and water flow rates, and the correction of malfunctions, can be carried out automatically.

The computer will store the preset limits for automation and will be able to compare the preset information with the real-time measurement from sensors in the field. Based on the comparison of the field data with the preset limits, the computer will modify the irrigation cycle accordingly and issue commands for the operation of water valves, boosters, injection of fertilizers, automatic backflush of filters, etc. If a leak or burst occurs, the computer will close the water supply to the area in question, preventing damage and saving water.

The computer will store daily, weekly, and seasonal water-related data and fertilizer schedules to aid in the planning of irrigation and fertilization. The computer can store information and different programs on a cassette tape. As often as needed, it can provide the user with a current printout of all the events in the field.

Improved Drip Systems

Two major innovations in drip irrigation are (1) its use for row crops, and (2) mobile, or traveling, drip or trickle irrigation systems. Both are still in the research and development stage but show great promise for increasing the efficiency of water use.

Since the inception of drip irrigation in California, it has been used mainly on trees and vines. During the last five or six years, there has been increasing interest and experimentation and some adoption of drip for row crops. The strawberry industry in California uses drip systems to a great extent, as does the sugar cane industry in Hawaii. At present, the field crop that appears most adaptable to drip is cotton. There have been many experimental plots using drip in cotton, ranging from 1 acre to 50 acres.

Row-crop drip systems differ from tree or vine drip systems in several ways. The number of hoses and emitters in the field is two to three times the number used for tree and vine systems. The submains and mains are usually not buried, and are made of a flexible material (lay-flat tubing). The hose or tubing that delivers the water into the soil can be of two types: long life or short life. Water is emitted from the tubing via small orifices spaced 12, 18, or 24 inches apart.

The choice of placing the drip tubing on or below the surface affects cultural practices, the tubing life, and the grower's confidence in delivery reliability. To avoid damage by farm equipment, surface systems cannot be installed until discing and other cultural practices have been completed. Thus, an alternative method of preirrigation is necessary, or the drip tubing will have to be removed following preirrigation and reinstalled following discing. Subsurface placement of the tubing should result in fewer weeds and pests, longer tubing life, and reduced surface evaporation.

In general, a grower may have more confidence in a surface system, because it can be inspected for clogging and other delivery problems quite easily. A sub-

Flexible Tubing Used for Submains in an Underground Drip System

surface system is more difficult to monitor; a suggested monitoring method for subsurface drip systems is aerial infrared photography.

The operation of subsurface trickle systems requires careful planning and management. Good filtration is a must and the system should be equipped with flushing valves to prevent plugging by fertilizers and impurities in the irrigation water. The system must be checked frequently to ensure that it is operating properly. The flushing valves should be opened immediately after installation to prevent plugging by soil and plastic particles. How often the system must be flushed will depend on the quality of the irrigation water and the rate of water flow through the system. The flow rate should be constantly monitored, since no moisture appears on the soil surface.

A subsurface system must be operated at least once daily to maintain the soil around the emitters near saturation. This will prevent roots, which do not proliferate in saturated soil, from entering the emitters. However, if the soil near the emitters should dry out, the roots will grow and eventually enter the emitters. If the system is to be turned off for an extended period, herbicides or fumigants should be applied to kill roots around the emitters.

Drip irrigation shows potential for water, energy, and fertilizer savings. Currently, subirrigation of cotton is being tested in Kern County to determine the effects on yield and whether it is a cost-effective investment for the farmer.

Low Energy Precision Application (LEPA). The LEPA system resembles a linear-move sprinkler system; in the LEPA system, however, conventional sprinklers have been replaced with drop tubes and emitters. The drop tubes place the emitters in the furrow about 3 to 4 inches above the soil surface; thus, the emitters simulate a gentle rainfall. The emitters are designed for an omnidirectional discharge of water over a 12- to 14-square-inch area and operate in the 1- to 15-psi range. The size of orifices along each manifold may be regulated to compensate for friction losses within the manifold.

In the initial stage of development, the system was called a mobile trickle system, in which a large number of small stationary emitters of the conventional trickle system were replaced with a small number of large moving emitters. The LEPA technique of irrigation is capable of very low-pressure operation while still maintaining highly uniform applications. Projected operating pressures vary from 4.5 to 22 psi, depending on the length of the system and flow rates. Distribution uniformities of 95 to 96 percent are also projected. A high degree of control over net application amounts is possible, primarily because of the speed at which the system moves.

The high degree of control can eliminate deep-percolation losses, and the spray evaporation losses from conventional sprinklers are essentially eliminated. Runoff can be minimized by effective tillage of the field, increasing the LEPA system application efficiency to upward of 98 percent. The combination of low operating pressures and high application and distribution efficiencies results in potential applied water and energy savings.

Irrigation Management

While there continues to be improvements in irrigation systems, the most important aspect to consider is how the system is managed to provide are adequate irrigation.

An adequate irrigation is one that refills the root zone storage capacity of the soil throughout a field. Virtually every irrigation system, no matter what kind or how it was designed, can apply an adequate irrigation. However, it does not necessarily follow that the water will be used efficiently. To apply water efficiently, the irrigation must be adequate and applied uniformly over the field. With an adequate irrigation, i.e. filling the root-zone soil moisture reservoir to field capacity, a system could still over apply water in different parts of the field, resulting in a nonuniform application.

An adequate but nonuniform irrigation on a soil with a slow infiltration capacity can mean the water will be in contact with the soil surface for a long time, long enough to inhibit air movement into the soil, which could harm the roots or scald the plants, if the temperature of the water should rise sufficiently. If the soil has poor internal drainage, i.e. subsurface barriers to downward movement, overapplication can result in waterlogging, restricting the amount of air in the soil available to the roots, which will severely harm the plant, and enhancing the environment in the soil for harmful pests and diseases. In addition, when drainage is poor, over application can build up a perched water table, which can lead to soil salinization and a smaller root zone. This can severely impair the long-range productivity of the soil.

Uniform application can mean high yields, uniform production across a field, uniform high-quality harvested crops, less risk of plant disease, less loss of fertilizers, and less applied water. However, it may not be profitable to the grower to strive for the highest level of efficiency that the irrigation system can attain. The grower must consider the costs of water, labor, energy, and fertilizer, costs of capital investments to improve the system, and the market price for harvested crops. A grower with a lower value crop may find it more profitable to operate at a 50 to 65 percent efficiency level than at a potential 65 to 85 percent level. Alternatively, a grower with a high-value crop may find it profitable to invest in his system and pay for managing it at a higher level, perhaps as high as 70 to 85 percent.

Regardless of the irrigation system, nonuniform application of water can result from several sources. With surface systems, a principal source -- not controllable by the grower -- is the nonuniform texture of soils within a field. In California, it is an uncommon field that does not contain at least two soils of different characteristics. Different soils usually have different infiltration rates. For uniform applications with surface systems, a grower must attempt to have water in contact with the soil surface for equal or nearly equal amounts of time on all areas of the field. This time is referred to as the <u>intake opportunity time</u>. If the system can be managed so that the intake opportunity time across the field is nearly-equal, or uniform, and if the soil and infiltration rates are uniform, the result will be uniform distribution of water in the soil throughout the field. On a field with nonuniform soils (and usually nonuniform infiltration rates), water will be distributed nonuniformly. Whereas the intake opportunity time may be uniform through the field, soils with higher infiltration rates will have more water enter the soil profile.

In fields with relatively uniform infiltration rates throughout the field, the biggest factor involved in uniform application is the intake opportunity time. In furrow irrigation systems, water is applied at the top end of the field and flows down furrows to the bottom end of the field. The time it takes for the water to travel to the end of the furrow is called the advance rate. The amount of time it takes for the water to recede from the furrows after the water is shut off is called the recession rate. Usually, this rate is quite fast, and because most soil infiltration rates decrease by the end of an irrigation, the time of recession is so small that it is often negligible.

The uniformity of application along the furrow is related to the advance rate and the total time of irrigation. This relation is expressed as the advance ratio , the ratio of time of advance to total time of irrigation. When a large nonerosive stream is applied in a furrow, the advance time should be small, and the intake opportunity time at the higher end will be only a little longer than that at the lower end, resulting in a very uniform distribution of water. As a common rule, an advance ratio of 1/4 to 1/3 will result in very good uniformity.

Thus, for furrow systems, sources of nonuniformity can be nonuniform soils within the field and operation with a large advance ratio. Other sources are fields that are not graded smoothly, or fields with low spots. After the water is shut off following an irrigation, water will not run out the end of a furrow but will sit in a low spot, increasing intake opportunity time at that area and decreasing uniformity. On systems without tailwater ditches to remove water from the end of the field, water will pond at the end of the furrow, increasing intake opportunity time and decreasing uniformity.

With many California soils where surface irrigation methods are being employed infiltration rates vary through the irrigation season. Most commonly, fields will have a high infiltration rate during the first part of the season and a gradual reduction of the rate through the season. This varying infiltration rate will affect the advance rate down a furrow, and hence affect irrigation efficiencies. High efficiencies are possible at the middle and end of the season, with lower efficiencies during the first part of the season. An evaluation of a system in this circumstance would need recommendations on how to manage the system through the whole season.

A measure of uniformity that is used in most irrigation systems is distribution uniformity expressed as a percentage:

$$\text{Distribution Uniformity (DU)} = \frac{\text{average depth infiltrated in lowest quarter of field}}{\text{average depth infiltrated on whole field}} \times 100$$

Generally, Distribution Uniformities of under 67 percent are considered unacceptable. For example, if the desired depth of water application is 4 inches and the Distribution Uniformity is 67 percent, the average depth infiltrated must be 6 inches, resulting in 2 inches of deep percolation. If, in this case, deep percolation is limited by reducing the applied depth, any area that receives the low quarter depth of irrigation will be seriously underirrigated.

The term Distribution Uniformity is used with surface systems and sprinkler systems. Another term, emission uniformity, is used as a measure of uniformity for drip irrigation systems. Emission uniformity, expressed as a percentage, is defined as:

Emission Uniformity =

$$\frac{\text{minimum plant discharge rate (average of the low quarter)}}{\text{average discharge depth per plant}} \times 100$$

General criteria for Emission Uniformities for drip systems that have been in operation for one or more seasons are: greater than 90 percent, excellent; between 80 and 90 percent, good; 70 to 80 percent, fair; and less than 70 percent, poor.

Graded border irrigation systems suffer from low uniformity, as do furrow systems, when the soils in the borders are not uniform or when there are low spots in the borders. For any border, there is a fixed recession curve, shown in Figure A/1. It becomes a control item for good uniformity. For excellent uniformity, the advance curve for a border must be very nearly parallel to the recession curve, also shown in Figure A/1. The vertical distance between the two curves at any point along the border represents the intake opportunity time. Therefore, with a uniform soil, this border example would have very high uniformity because the intake opportunity time was very uniform along the distance of the border.

With border strip irrigation, the water is turned into the top of the border and allowed to flow about 60 to 80 percent of the distance down the border before it is turned off. The water in the upper end continues down to the end and irrigates the lower end. If the stream is too small the advance rate is very slow, resulting in a larger intake opportunity time at the upper part of the border and a lower uniformity. Too large a stream can result in too much water at the lower end of the field. Border length can also affect uniformity as can the distance down the border when the water is cut off.

Both sprinkler and drip irrigation systems are unique in contrast to surface systems in that they can be independent of soil uniformity and topography in their adaptability. Systems should be designed to apply water to the soil at a rate lower than the lowest infiltration rate of the soil in the field. If this is not done, then some of the applied water will not immediately infiltrate the soil and flow over the surface to low spots, resulting in lower uniformities. Pressures will vary within the

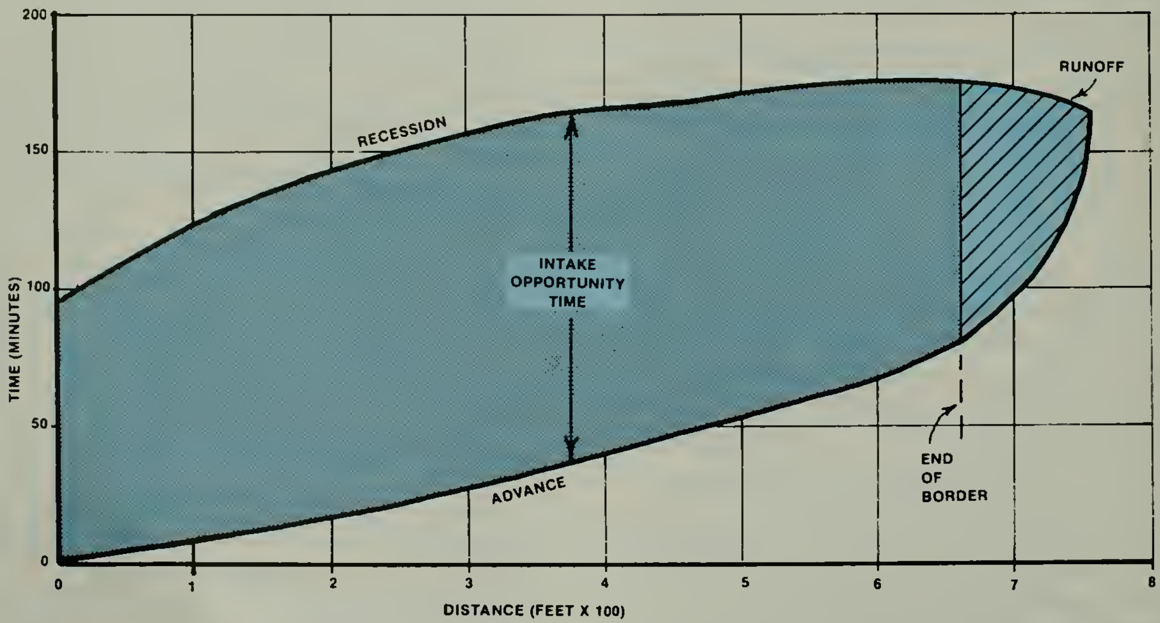


Figure A/1. Advance and Recession Curves for Border-Strip Irrigation

system, because there are always friction losses within the pipelines, and elevations may vary as well. Usually, a system is designed to have a pressure differential of approximately 20 percent. However, actual values depend on the equipment used and whether it is economical to design to that tolerance. As pressure differentials within a system increase, the level of uniformity decreases.

Sprinkler system are designed with sprinklers spaced close enough to allow for spray overlap. Figure A/2 illustrates sprinkler spray patterns and overlap, and the resulting application. If sprinklers are spaced further apart, the overlap is reduced, the application will be less uniform, and more water will be applied close to the sprinklers than between them. Wind can seriously affect uniformity. The spray pattern can be drastically changed when wind interferes with the flight of the droplets in the air. When this occurs, more water is applied downwind of the sprinkler, with an accompanying low level of uniformity. This can be very substantial with sprinklers at high pressure, where droplet sizes are smaller and moved easily by wind.

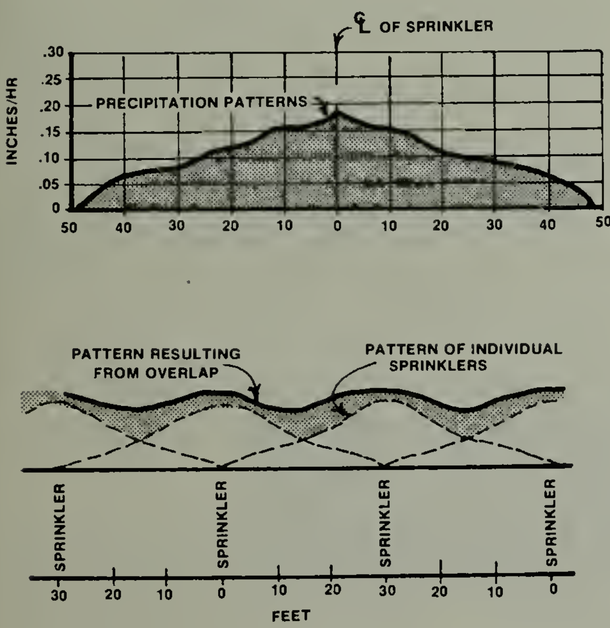


Figure A/2. Overlap of Sprinkler Spray Patterns

System Evaluations

Growers who want to determine whether their irrigation system(s) are being operated efficiently and with good uniformity have two choices: perform a simple evaluation themself or arrange for a full evaluation from a qualified source.

Evaluation by a Grower. The first step in a grower's evaluation of a furrow system is to determine the soil moisture content of the root zone before irrigation. This can easily be done by sampling the soil at various locations in the field, using a soil sampler or auger. Soil at specific depths (0-1 ft., 1-2 ft., etc) is brought to the surface. Then, the approximate amount of moisture at that depth is determined by comparing its appearance to a "Soil Moisture Appearance Relationship Chart". The soil is sampled down to the bottom of the crop root zone.

Soil Moisture Determination Using the Field Method

The various moistures at each depth for the entire depth of rooting are added together and then subtracted from the field capacity for the root zone. The resulting number is called the soil moisture deficiency or SMD.

The SMD should always be the first concern - is it dry enough to irrigate? A field should be irrigated when the SMD is nearly equal to the management allowed deficiency or MAD. The MAD is determined by the grower, using information such as root depth, water holding capacities, climate, crop, etc. Usually the MAD is around 40 to 60 percent of the maximum available moisture in the soil. For example, a corn crop might have a 4-foot root zone, available water of 1.8 inches per foot, and the grower is willing to let the soil dry out to 60 percent of total available water. This would result in a MAD of 4.3, calculated as follows:

MAD = 1.8 inches/foot x 4 feet x 0.60
= 4.3 inches

The grower should irrigate when the SMD is almost equal to MAD, 4.3 inches. If irrigations are scheduled before MAD on a regular basis, more irrigations and associated labor costs will occur during the growing season. If SMD is greater than MAD when an irrigation occurs, the crop will be stressed and yield losses can result.

The grower should also probe the field after irrigation. Checking the soil moisture throughout the field will determine if the irrigation was adequate (did the irrigation wet the soil down to 4 feet?) and if it was uniform. If the results of probing show that the upper ends of the furrow received water to 5 feet, and the lower ends received water only to 2 feet, it would be obvious that the uniformity was poor. In this case, it can be surmised that the intake opportunity was much greater at the top than the bottom of the field, due most likely to a large advance ratio.

A grower could also determine uniformity by collecting data to calculate the advance ratio. This is done by monitoring the time necessary, from the start of the irrigation, for the water to travel to the end of the furrows, which is the time of advance. The total duration of the irrigation would also be recorded. The advance ratio would be the ratio of the time of advance to the time of irrigation. In the previous example, the advance ratio probably would not be in the 1:4 range, which is considered ideal for uniformity. If a grower measured a small advance ratio, e.g., 1:9, the water reached the end of the furrows much faster than is needed for excellent uniformity. It would also mean that runoff would be excessive, although if a tailwater recycling system were used, the water would not leave the grower's field.

There are simple methods for both sprinkler and graded border irrigation systems, which also entail some easy monitoring of time, soil moistures, and pressures. A grower could make simple evaluation of these systems to determine whether irrigation is adequate and uniform.

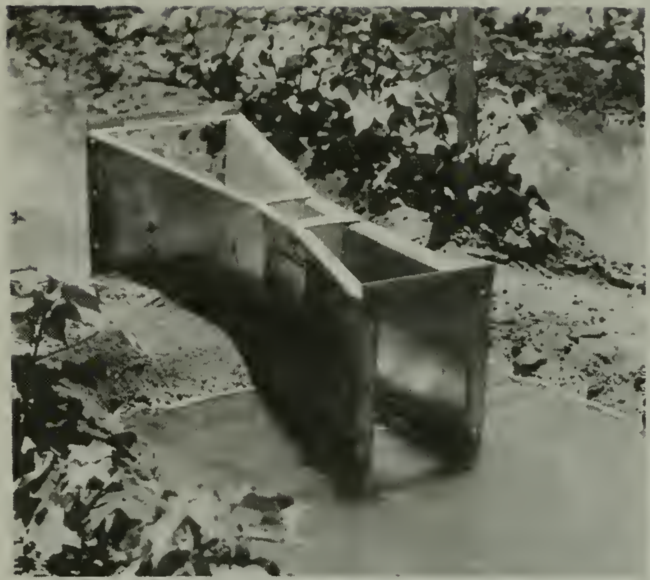
Evaluation by an Irrigation Consultant. Growers can obtain a full evaluation of their fields which would give them much more information. The evaluation would result in some calculated number of distribution uniformity and application efficiencies, among others. Also, recommendations would be provided on how to improve his operation to make the best and most efficient use of labor, energy, water, and other production inputs. This kind of in-depth evaluation is available through private consultants and, to a limited extent, through public agencies.

The full evaluation of a furrow irrigation system is quite complex, with many measurements in the field to be taken and many calculations to be made. The use of a computer program is not essential, but would certainly save many hours of hand calculations.

Before an irrigation is begun on a field to be evaluated, some preliminary work must be done. The furrows to be tested are selected, stakes are placed at 100-foot intervals along each furrow, and flumes or orifice plates are set in the furrows. These water-measurement devices are set at about 15 feet from the top of the furrow, 100 feet down- stream from the top flume, and at the lower end of the furrow, for each furrow. Usually, a total of three furrows are tested. One is tested at the flow rate the grower usually uses, one at a lower flow, and one at a higher flow. The soil of the field is sampled to determine moisture content. This is used to determine the SMD, and to see if the SMD is nearly equal to the MAD.

When the irrigation begins, the intense monitoring begins. As the water flows down the furrows, the time it reaches each stake is recorded. The flow across the flumes or orifice plates is recorded throughout the test, as well as time intervals. Observations must be made at each furrow to determine if the furrows are being eroded by the streamflow.

After the irrigation, soil moisture samples are taken again to determine the adequacy of the irrigation. Then the graphing and calculations, using the field data, are begun. Basically, the difference in water flow at each flume is used to determine intake rates of the soil. Then the data collected on the times the water stream reached the stakes in the field are used to determine the intake opportunity times along the length of the furrows. A depth infiltration curve can be developed using the intake opportunity times and infiltration rates. An example of a curve is given in Figure A/3.



Parshall Flume in a Furrow to Measure Streamflow (photo by U. S. Soil Conservation Service)

With the information derived from this curve, the distribution uniformity can be calculated. Also, the application efficiency can be calculated, and the amount of runoff and deep percolation determined. A depth infiltration curve would be developed for each of the three furrows tested.

The consultant would then analyze the findings to determine what a grower could do to improve application uniformity and efficiency if improvement is

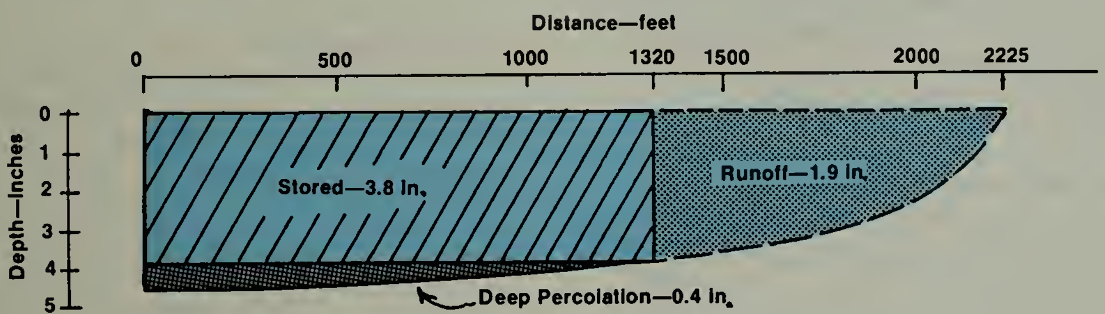


Figure A/3. Infiltration Curve

needed. This might be a larger stream size, tailwater recycling, cutback of furrow streams, adjustment of MAD, reduced furrow lengths, and many more. Once the determinations are made, they must be looked at individually to see if they could be fit into the grower's operation and what the possible costs and benefits to the grower would be.

There are, at present, very few consultants that perform system evaluations. The costs of evaluations range from $500 to $1000 per system. The actual price would depend on the type of irrigation system and the size of the field.

Evaluation by Water Agencies. During the summer of 1981, both the El Dorado Irrigation District and the Pond-Shafter-Wasco Resources Conservation District (RCD) implemented small programs, funded by the Department of Water Resources, to provide growers within the districts with information on irrigation water management. Specifically, agency representatives visited grower's fields and conducted irrigation system evaluations, explained the results, and made recommendations, when possible, on how to improve the efficiency of water use.

The Pond-Shafter-Wasco RCD is located in the southern San Joaquin Valley in Kern County. Eleven evaluations, all of surface systems, were made during the summer months. Technical guidance and program management was supplied by Soil Conservation Service personnel. In each evaluation, a four-member team performed the field work necessary during an irrigation set. The data collected was then used in equations and graphs, resulting in numbers of advance ratio, distribution uniformity, and application efficiencies.

Based on the results, recommendations were prepared for the grower on how to improve the efficiency of water use. The recommendations included decreasing applied water, using water-budget scheduling available through consultants, decreasing preirrigation, installing a tailwater recycling system, converting from spiles to gated pipe, and increasing furrow streams. In some cases, where sound management practices already existed, the team made no recommendations at all.

El Dorado Irrigation District is located east of Sacramento in the Sierra Nevada and foothill region, where most of the irrigated acreage is located. The crops grown in this area are mainly tree crops, with some vines and pasture. Almost all the tree crops are irrigated with sprinklers. For many years, the District has had an irrigation scheduling program, called Irrigation Management Service or IMS, developed with assistance from the U. S. Bureau of Reclamation. This program helps growers decide when to irrigate and how much water to apply. By knowing his sprinkler application rates, a grower can easily apply the recommended quantity of water. The District found that in many cases growers needed to determine sprinkler application rates in order to successfully use the scheduling program's recommendations. The 1981 program was intended to help solve that problem.

A total of 328 evaluations were conducted of overhead, under-tree and portable irrigation systems. Full evaluations were conducted of the overhead and under-tree permanent sprinkler systems. The portable systems were found to be operating at such a low efficiency level that a simple evaluation would be much more productive than full evaluations.

The problems found with the sprinkler systems were varied. Many were found to have excessive operating pressure, which produces a fogging effect. In other cases, pressures were too low to permit operation within the manufacturer's specifications. Variations of pressure along laterals were too large to be acceptable in many cases. Worn nozzles were common, as were mismatched components (different size sprinklers or nozzles within a system). Excessive runoff was also a problem in some fields. Leaky gaskets at pipe connections contributed to the problem as well.

After all the systems had been evaluated, the results and recommendations were delivered to the growers. Some growers reacted to these recommendations and refurbished their systems, others adjusted their irrigation sets to match scheduling recommendations, and some changed to microsprinkler systems.

Another major benefit of the program was the educational aspect. The growers gained increased knowledge of their systems, their operation and management practices, and their systems' strengths or deficiencies. The program also aroused the growers' curiosity on how their systems might be improved, for example by changing to a system or improving their management practices.

Following the program, El Dorado Irrigation District concluded that most participating growers had gained new insight into water management, but that most of them may not have had time to appreciate the potentials of improved irrigation practices. In addition, the district believes that implementation of the recommended changes will be constrained by the cost, labor, and time required to put them into effect. The District's overall conclusion was that irrigation practices within the district can be upgraded only after a long-term educational program and additional supporting programs.

As a result of the 1981 evaluation program, the District has developed a special cost-sharing program to demonstrate the long-term potential for water conservation. The district will receive partial funding from the U. S. Department of Agriculture's Agricultural Stabilization and Conservation Service to conduct the program on three participating farms. Information developed during the 1981 evaluation program will be used to upgrade the irrigation systems of the participating growers, and crops will be changed to crops that use less water. Total on-farm water use before and following the changes will be documented to determine the applied water savings potential of the new practices.

The Department's Evaluation Programs. Recently, the Office of Water Conservation developed an educational and demonstration program involving irrigation systems operation and management. The program, the Interagency Mobile Agricultural Water Conservation Laboratory or Mobile Labs, funded by the State Water Resources Control Board, is being carried out in the field in cooperation with the University of California Cooperative Extension, Soil Conservation Service, the California Association of Resource Conservation Districts (CARCD), and various individual Resource Conservation Districts.

The purpose of the program is to inform growers of irrigation system evaluations, demonstrate how evaluations are performed, explain how on-farm efficiency can be increased, and provide information on irrigation scheduling programs and techniques.

Each mobile lab consists of a truck or a van containing the necessary tools and equipment to properly evaluate all types of irrigation systems: furrows, graded borders, sprinklers, and drip. The labs are staffed by three to four crew members who perform the evaluations in the field. The representatives of the cooperating agencies, the farm advisors from the Extension Service, the District Conservationists from the Soil Conservation Service and personnel from Resources Conservation Districts and Irrigation Districts, help locate and schedule participatants for the program. Initial one-time system evaluations are provided to ensure that a maximum number of growers will be contacted. There are also planned demonstrations where groups of growers can observe the mobile lab in operation and have the program explained.

The extent of the evaluation--simple to full--depends on the system itself, the soils, and the existing management practices. Before the evaluation, information is gathered about the existing operation and on the physical layout of the field, the topography, the soils, etc. The Mobile Lab team leader, the District Conservationist, the farm advisor, and the irrigation district personnel then decide what kind of evaluation would be most productive for that field. The system is evaluated and the data collected is used to calculate the advance ratio, distribution uniformity, and irrigation efficiencies. Based on these results, recommendations for improvement would be developed and explained to the grower. If the grower decides to follow the recommendations, then a followup evaluation may be performed to determine the effectiveness of the improved practice.

During the first season, 1982, two mobile labs were operated. One was in Imperial Valley, with the Extension Service acting as the lead agency, and the other was in the southern San Joaquin Valley, with the California Association of Resource Conservation Districts as the lead agency. During the next two irrigation seasons four mobile labs will be in operation. At the end of this three-year project, it is hoped that the demand for irrigation system evaluations will increase, which should stimulate the private sector to provide more such services.

Improvements Following An Evaluation. A grower whose irrigation system has been evaluated should receive not only the results of the evaluation but also recommendations on how to increase the efficiency of the system. Only in very extreme cases would the recommendations call for a complete change of system (for example, changeover from furrow to sprinkler, or sprinkler to drip, etc.). Once the recommendations are made, the grower must decide which improvements to make, if any.

The recommendations for improvement might be management changes, operational changes, or physical changes. The costs to implement those would vary widely, from almost zero to perhaps $200 per acre. The most probable and widespread management change would cost the grower very little, and perhaps nothing, to implement. This would be to irrigate when SMD approaches a properly determined MAD. Growers would most likely irrigate before MAD (irrigating after reaching MAD might produce visible plant stress), resulting in overirrigation and excess deep percolation. To irrigate at the MAD, the grower would have to schedule irrigations using either the soil monitoring method or the water budget method. Both services are available from private consultants at $4 to $10 per acre. Growers could also schedule irrigations themselves by using a soil sampler and using the soil moisture method. This may cost a little to implement but would have some significant benefits, such as reduced fertilizer losses, reduced water costs, and, most significantly, reduced labor for irrigation (fewer irrigations per season may be required).

An improvement in a hand-move sprinkler system that would increase DU and cost nothing is the use of "alternate sets". In this practice the regular move distance and frequency are used each time, but at alternate irrigations the starting location for the lateral is midway between the previous sets. The high application area of the first set tends to compensate for the low application of the alternate sets. Duration of irrigation must be changed because of increases in efficiency. Wider than normal move distance could also be acceptable with this practice. Labor would remain the same, but because of increased uniformity, savings in applied water, energy, and fertilizers are possible.

A graded border system can be highly efficient with very high distribution uniformities, but is not as efficient for irrigating an annual crop, which has an expanding root zone. Graded borders are very efficient in applying a certain depth of water, usually 3 to 6 inches. An evaluation of an early season irrigation would reveal low efficiencies due to overirrigation (deep percolation). In this situation, there could be two different recommendations for improvement. One could be to not preirrigate, and use the excess water applied during the early irrigations to refill the root zone. This would reduce costs because no labor or water would be needed for preirrigation. This practice would not be suitable in all situations, however. Another recommendation would be to use portable pipe in the middle of the field to divide the field in half, thereby shortening the strip length. Using portable pipe along with the original system to irrigate the field during the first part of the irrigation season can significantly improve irrigation efficiencies. This would involve a capital cost for the portable pipe, and an additional cost for labor.

Permanent sprinkler systems may not deliver water uniformly on irregular terrain because of excess pressure variation. An evaluation may well result in a recommendation to install pressure regulators in the system. The cost would depend on the price per regulator, the number of regulators needed, and the labor required to install them.

An evaluation of a furrow, graded border, or level basin system might result in recommendations to laser-plane the field to eliminate low spots. Irrigation water will collect in low spots and reduce distribution uniformities and efficiencies. The costs of leveling a field would be about $50 per acre or greater, depending on the amount of soil that would have to be moved.

An evaluation of a surface system on a soil with a slow infiltration rate could result in recommendations that may not save water but increase water use. This has happened in the past when an evaluation revealed that the soil would not take water fast enough during an irrigation. The recommendation was to apply gypsum to displace sodium with calcium ions on the soil particle surfaces. This increased infiltration, the irrigation system could then apply an adequate irrigation, and water use increased. It is also possible that production increased as well.

Evaluations of any system would virtually always result in recommendations of employing some method to determine the actual amount of water that is applied to a field, if no such method was used previously. Even if irrigations are scheduled properly, irrigation system efficiencies known, and total amount of water to be applied during on irrigation is determined, without some sort of water measurement method, it is difficult to apply the correct amount of water. Measurement devices, such as propeller meters used in pipelines or weirs and flumes used in ditches and canals, can measure water flow directly and accurately. Less accurate methods can be used, such as determining flow rates in siphon tubes by using the difference in elevation between the water surfaces in the supply ditch and the furrow. Also, flow from wells can be estimated using information from a recent pump test. Knowledge of amounts of water applied during an irrigation is essential for good irrigation management.

There are many solutions to uniformity and efficiency problems involved with irrigation systems. The costs and increased management can vary greatly. Before managers decide on an improvement, they would be wise to consider: (1) the value of the water in terms of its cost or in terms of its productiveness when the water supply is limited, (2) the cost and skill of labor, (3) the capital investment, and (4) the problems caused by runoff and deep percolation.

Irrigation Scheduling

The critical interrelationship between soil moisture, crop water requirements, and the growth of healthy plants has led to the development of irrigation scheduling, to more precisely determine the quantities of water needed by plants at the right time. California growers use a variety of methods to schedule irrigations, all of which require different levels of management input and different monitoring methods. Regardless of the method used, the objective is the same: to determine (1) when irrigation is needed, and (2) how much is needed to refill the soil root zone. Discussed here are:

- the calendar method
- the plant observation method
- the plant status
- the control comparison method
- the soil moisture sensing method
- the water budget method

Calendar Method. The most common scheduling technique is the calendar method. Basically, irrigation dates or intervals are determined early in the season, usually after the crop has been planted. The intervals between irrigations are sometimes dictated by the district supplying the grower with water. For example, it is not uncommon for alfalfa growers to receive water at 2-week intervals, or at 10-day intervals when the crop is a grain. They might also use the calendar method based on past experience with the crop, regardless of year-to-year weather variations.

With the calendar method, there is one less management decision to make--when to irrigate. Where the soil is deep and loamy and the crop is deep-rooted, the calendar method may be adequate, with no reduction in yield due to stressing. The grower would probably apply excessive water to ensure adequate irrigation and avoid crop stress.

A disadvantage of the calendar method is the possibility of crop stress between irrigations in a field with shallow soils or shallow-rooted crops. A second disadvantage is that a grower cannot determine how much water is needed to replenish the plant root zone.

Plant Observation Method. Some plants, beans for example, exhibit sufficient color change to permit scheduling on the basis of appearance. Other indications are curled leaves and leaf wilting. Many crops, however, do not show consistent visual effects of low soil moisture to indicate that irrigation is needed. Growers using the method usually have had much experience with the crop and probably have had reasonable success with it.

The plant observation method is quite subjective, however. The risk involved is that by the time the visual effects are apparent, yield or quality may have already been adversely affected. As with the calendar method, determination of how much water is needed to refill the root zone cannot be made.

Plant Status Method. Plant status measurements can also be used to schedule irrigations. In this method, certain crop parameters are measured continuously and when the measurements approach a predetermined level, an irrigation is applied. Two instruments used predominently with this method are the pressure bomb and the infrared thermometer.

Research on water stress and plant physiology over the past 15 years had revealed that leaf water potential can be used as an indicator of plant water stress. The leaf water potential can be estimated with the aid of a pressure bomb. This instrument measures the water tension in xylem tissues, which has been found to correlate well with the leaf water potential.

The pressure bomb consist of a pressure chamber connected to a supply of pressurized nitrogen gas, with a valve and pressure gauge in between. A leaf is cut from a plant and quickly inserted into the pressure chamber, with the leaf stem or petiole protruding from the chamber via a sealable orifice. The valve is opened, allowing nitrogan gas to enter the chamber. The gauge measures the pressure in the chamber. As the chamber is pressurized, the cut end of the petiole is observed. When sap is observed coming out of the petiole, the valve is quickly closed and the pressure-gauge reading is recorded. This pressure reading, in atmospheres, is the estimate of leaf water potential.

Measurements using the pressure bomb should be made before dawn, when the plant water is in equilibrium with the soil water, and movement of the water from the soil into the plants is minimal. Predawn measurements of plant water potential have been shown to correlate well with measurements of soil water potential. Research with cotton has shown that midday (between noon and 2:00 p.m.) readings of plant water potential can be used to schedule irrigations. In the San Joaquin Valley, research with cotton has resulted in recommendations of midday plant water potential readings not exceeding 22 to 23 atmospheres.

Daily or every-other-day readings are plotted on a graph of time versus plant water potential. A horizontal line (parallel to the time axis) is drawn at the 23-atmosphere level. The point on the graph representing readings are connected by a curve and extrapolated to cross the horizontal maximum line. A vertical line drawn downward from this intersection would intersect the time axis at the estimated date of irrigation. At present, several large farming operations are using the pressure bomb to schedule irrigations on cotton fields.

Infrared thermometry is also being researched as a tool for irrigation scheduling. This is a noncontact method for determining the surface temperature of temperature of an object. Infrared thermometry can be reliably used (with due regard for calibration) to measure the surface temperature of crops. The method is very promising; however, there are many problems still associated with infrared thermometry hardware and software that require experienced judgments.

Crop water stress can be inferred with the use of infrared thermometry. The concept of a crop water stress index requires the simultaneous measurement of vapor pressure deficit. The stress index is the ratio of (1) the difference between the canopy and air temperatures at a specific vapor pressure defecit to (2) the difference in these temperatures for the "well-watered" and "extreme stress" cases. A stress index has a value of 0 for no stress and 1 for total stress. In the San Joaquin Valley, research has shown stress index to be linearly related to lint yield in cotton. Based on this work, the average stress index should not exceed 0.3 to achieve a very good yield. In this case, stress index would be monitored routinely and plotted on a graph of time versus stress index. Data points would be connected and drawn to intersect the 0.3 stress index horizontal line. The point of intersection would represent the irrigation date.

Control Comparison Method. Another method that can be used with infrared thermometry is control comparison. This involves the simultaneous measurement of the field in question and a "well-watered" field. The control field would be a field that has just been irrigated. Irrigations would be initiated at a temperature difference of 2° to 3° C.

The canopy temperature measurements are taken with a hand-held infrared thermometer, an instrument resembling a pistol. The thermometer is aimed at the field a little below the horizontal, and the readings are taken. The canopy temperature measurements should be taken between 1:00 and 4:00 p.m., which is usually the period of maximum daily plant stress.

Both the infrared thermometry and pressure bomb methods can be effective tools to determine when an irrigation is needed, although neither will indicate how much water is needed to refill the root zone.

Soil Moisture Sensing. This is another method quite commonly used to schedule irrigations. No matter what equipment is used, the principle of operation is the same. The soil is monitored routinely with the measurement equipment. Irrigations are scheduled when the soil moisture approaches a predetermined level. The amount of water needed to refill the root zone can be determined directly or indirectly from the measurements.

Several different types of equipment can be used to determine soil moisture. The most rudimentary is an auger or sampling tube to bring a sample of soil to the surface. The soil can be analyzed gravimetrically (dried in an oven to determine moisture content), or moisture can be determined by the field method. The soil sample is compared with a soil-moisture-and-appearance chart to determine the approximate moisture content.

Electrical resistance units, or gypsum blocks, buried in the soil indirectly measure soil moisture tension in the surrounding soil. Inside the block of gypsum is a resistance unit, which varies in resistance with changes in moisture. The moisture content of the block is controlled by the tension of the soil. An electrical potential is applied to the block via wires at the soil surface and a meter reading is taken. This reading is then converted to soil moisture tension with a calibration curve. Generally, the units do not work well below 100/-centibars (cb) of tension, and thus are not adaptable to crops that require higher levels of moisture.

Neutron probes are used to determine soil moisture by agricultural consultants and large farming operations. The principle of operation is as follows: Fast neutrons from an americium-beryllium source lose energy in elastic collisions with hydrogen (in the form of water in the soil). The collisions reduce the energy of the fast neutrons, converting some to slow, or thermal, neutrons. A sensitive detector is used to detect and count these slow neutrons. The count rate is an indication of the moisture content in the soil.

As part of the procedure, an access tube (aluminum, steel or plastic) is placed in the soil with one end protruding about 6 inches above the soil surface for the irrigation season. The instrument used is carried to each site and placed on the tube. The probe contain-

Neutron Probe Used for Soil Moisture Determination ing the radioactive source is lowered to the depth to be measured and a 15- to 60-second count is activated. The count is then converted to a moisture figure, usually in inches of water per foot of soil.

Tensiometers are very commonly used by growers to determine soil moisture tension. They consist of a closed tube with a hollow ceramic tip at one end and a vacuum gauge at the other. The tube is filled with water and installed in the soil, with the vacuum gauge extending above the ground. As the soil dries, it draws water through the ceramic tip, creating a partial vacuum inside the tensiometer. This is indicated on the vacuum gauge. As water is added to the soil, water is drawn back into the tensiometer, lowering the reading on the gauge. The gauge reads in negative centibars, with good accuracy in the 0 to 80/-cb range.

Irrigations can be scheduled with a tensiometer, as with other instruments indicating moisture levels in terms of soil moisture tension, although quantities of water to be applied are not determined directly. Soil moisture tension can be converted to volumetric figures (inches per foot) providing the moisture release characteristics are known for that soil. Agricultural laboratories can perform the soil analysis necessary to determine moisture release curves.

Tensiometer Used for Moisture Tension Determination

<u>Water Budget Method</u>. The water budget method of irrigation scheduling keeps track of how much water a crop uses just like you keep track of how much money is in a checking account. The amount of water in soil that is available to the crop at any time is called available water. Crops remove available water from soil through a process called evapotranspiration.

The water budget keeps track of how much water the crop removes from soil each day. When the crop has removed a predetermined amount, called the allowable depletion, then it is time to irrigate.

The allowable depletion is determined basically by the following equation:

$$\text{Allowable Depletion} = \text{AWxRDx\%AD}$$

where AW is the available water holding capacity per unit depth of the soil, RD is the rooting depth of the crop, and %AD is the percentage of available water that can be extracted from the profile without causing a loss in crop yield. %AD depends on several factors: plant factors (rooting density and developmental stage), soil factors (AW and soil depth), and atmospheric factors (current ET rates). No one single level of %AD can be recommended for all situations. Deep-rooted perennial crops on deep loamy soils under mild weather may use a %AD of 80 percent without reduction of crop yield. A crop with shallow and low density roots in an area of high evaporative demand may need a %AD of less than 40 percent.

To estimate ET of a particular crop at a particular stage of growth, this relationship is used:

$$ET_c = K_p \times ET_o$$

where ET_c is ET of the crop, K_p is an experimentally derived crop coefficient, and ET_o is a reference ET value. ET_o is defined as the evapotranspiration of close-clipped grass. This figure can be derived using a standard class "A" evaporation pan or from complex equations using weather data (collected from a weather station) including wind speed, humidity, solar radiation, and more.

In various parts of the State, ET_o data is available to growers through radio or local newspapers, or through irrigation districts. Many times, this information would also include ET estimates for the various crops grown in the area.

Irrigation Scheduling Services

In California, irrigation scheduling services are available from a number of sources. A number of private agricultural consultants offer scheduling services throughout the State. Some irrigation districts have their own scheduling programs and offer them to growers within a district. The U. S. Bureau of Reclamation has a program to help irrigation districts receiving federal water establish an Irrigation Management Service (IMS) to provide scheduling information to growers within each such district. The University of California Cooperative Extension has an irrigation management program (IMP), a basic irrigation schedule used as a planning guide.

Private Consultants. An increasing number of private consultants offer scheduling services to growers for a fee. The scheduling methods used are the plant status method (pressure bomb), soil moisture method (neutron probe, tensiometer, gypsum blocks, and the "field" method), and the water-budget method. The majority of consultants offer scheduling services in one package with fertilizer or plant nutrition services also.

Consultants using soil moisture or plant status measurements as a basis for irrigation scheduling set up a monitoring program for each field being scheduled. The fields are usually monitored at least twice a week or more during the hot part of the season. Data are collected and entered into a graph or table, in usable form, and presented to the grower, along with recommendations on when to irrigate and how much water to add to the soil. Personal contact between consultant and grower is very important if the grower is to understand the information and have confidence in both the information and the consultant.

Consultants using the water-budget method also employ a field check program. With the water-budget method, it is assumed that a scheduled irrigation will be sufficiently adequate to refill the root zone. The field checks (soil moisture monitoring) are conducted to determine whether the last irrigation was adequate; if it was not, the irrigation schedule must be changed.

The field checks are also used to verify the accuracy of the scheduling predictions. Most consultants will alter the crop curves relating ET to crop ET following their investigations to adjust for local conditions. If a consultant has been scheduling a grower's field for an adequate length of time (a few years), the field check program can be reduced, providing the accuracy of the scheduling predictions have been verified.

The Bureau's Irrigation Management Program (IMS). The Bureau's IMS program has been in operation for ten years in California. The program is conducted in districts that receive Federal water and that want to establish IMS for their growers. The IMS program provides irrigation scheduling information to participating growers. Scheduling is based on the water-budget method (originally developed by Dr. M. E. Jenson from the U. S. Department of Agriculture). A computer program is set up for the district, weather information is gathered from a district-established weather station, and a field monitoring program is implemented. Field personnel make weekly visits to growers to deliver computer printouts, recommend irrigation schedules and advise growers on water management problems.

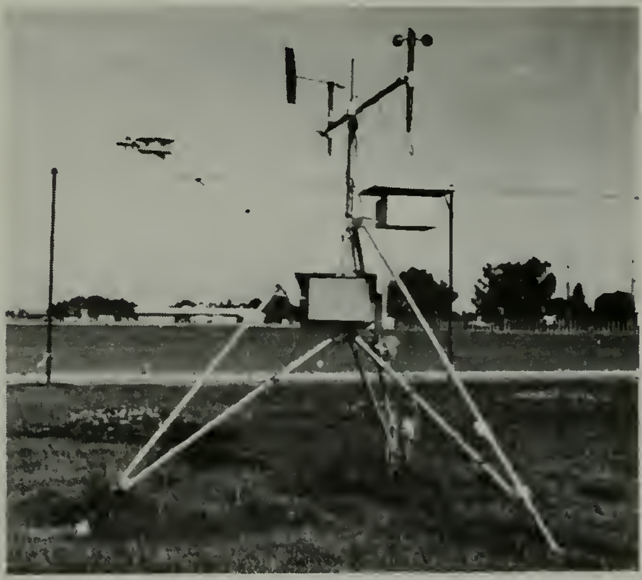
During a three-year demonstration program, the Bureau provides personnel, monitoring, computer equipment, and technical expertise to districts to operate the IMS. After three years, the program is to be conducted solely by the district. An objective of the program is to demonstrate the benefits of IMS such that the irrigation district will assume financial and operational responsibility. The IMS program in the Yolo County Flood Control and Water Conservation District is the most recent demonstration program which concluded in 1982. Solano Irrigation District, El Dorado Irrigation District, and Westlands Water District have now assumed responsibility for their IMS programs. The Tranquility and James Irrigation districts terminated the program after the initial phase conducted by the Bureau.

El Dorado's and Solano's programs are technically similar. Predictions are developed from a computer model using weather station data, and field checks are employed to verify the predictions. Over half the irrigated acreage in El Dorado Irrigation District has been scheduled using the IMS program. In Solano Irrigation District, fewer than one percent of the growers, who operate about 10 percent of the irrigated acreage participate in IMS.

The Westlands Water District has continued the IMS program after altering it significantly. In Westlands, IMS is now a guidance program, under which a "Water Use Guide" is sent to each participant in the district. The District is divided into three climatic areas; each week, every grower is mailed the representative crop ET's for the past forty days, and the ET forecast based on long-term records to assist the grower in planning irrigations. The individual field check program by the District has been completely eliminated. Westland's guide is not tailored to the specific situation of each individual field, as a water-budget program with the field checks would be needed. The District, in 1982, began conducting workshops to help growers use this information.

Some of the larger farms in the southern San Joaquin Valley have developed or are currently developing programs to schedule irrigations. Some use the soil moisture method, and some are incorporating a water-budget method approach. Large farming organizations may hire personnel to develop and manage an irrigation scheduling program, or they will have a consultant develop a program and train the organization on how to manage it. Weather data is obtained from radio stations, newspapers, local state agencies, or an established weather station.

University of California Irrigation Management Program (IMP). The University of California, under agreement to the Department of Water Resources, has developed an irrigation scheduling tool -- the Irrigation Management Program or IMP. The IMP employs the water-budget method but is developed before the irrigation season begins, using long-term weather data averages. Field information (crop, soil water-holding capacities, allowable depletions, and so on), crop coefficients, and average yearly ET_o values are entered into the



Automated Weather Station Used in CIMIS

IMP computer program and a printout is made shown in Figure A/4 depicting an irrigation schedule for the whole season. The schedule will work well, with field checks of soil moisture, during normal weather. The schedule is easily updated by integrating current weather data or ET_0 data. The IMP is a good guide for preseason planning, and will work well if it is used carefully. The Extension Service makes the IMP available to interested growers.

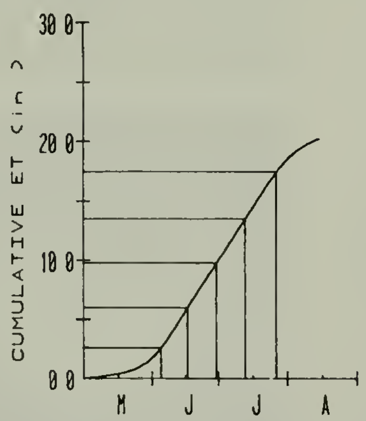
California Irrigation Management Information System. The California Irrigation Management Information System or CIMIS is a three-year research and development project, undertaken by the University of California's Cooperative Extension Service and Agricultural Experiment Station for the Department of Water Resources. The project will research the use of computer-generated irrigation scheduling information by selected growers in different areas of the State.

CIMIS will consist of a network of about 40 automated weather stations in five agricultural areas of the State: Imperial and Coachella Valleys, the southern San Joaquin Valley, Westside San Joaquin Valley, the Salinas and Pajaro valleys, and the Sacramento Valley. These stations will send daily weather information by phone lines to the main computer in Davis. The weather information will be used to calculate potential or reference ET data.

Seasonal irrigation progams will be developed for each grower participating in the project. Researchers from the University of California will monitor on-farm soil and crop parameters, which will be transmitted to the main computer, along with updated weather information. The computer will use this data

IMP FOR BEANS IN THE SAN JOAQUIN VALLEY

PLANTING DATE-MAY SOIL DEPTH-M ALLOWABLE DEPLETION-4 0 IN



IRR DATE (D A.P)	CUM. ET (in.)	AMOUNT TO APPLY (in.)
34	2.6	2 6
46	6.0	3 4
59	9.7	3.7
72	13 5	3 7
86	17.4	2 9

ET FOR A NORMAL YEAR

DATE	EPAN	Kp	ET	CUM ET
MAY 1-15	3.00	0 11	0 42	0 42
MAY 16-31	4 54	0 31	1 41	1 83
JUN 1-15	4 68	0 86	4 02	5 85
JUN 16-30	4 92	0 89	4 38	10 23
JUL 1-15	4 92	0 89	4 38	14 61
JUL 16-31	5 04	0 79	3 98	18 59
AUG 1-15	4 32	0 41	1 77	20 36

Figure A/4. An Irrigation Schedule Produced by the IMS System

to prepare updated irrigation schedules. This information will be accessible from the main computer by field terminals via phone lines.

Objectives of the program are to:

1. develop a network for weather data acquisition to compute real-time estimates of evapotranspiration;

2. develop an information delivery system for the dissemination of irrigation scheduling information;

3. integrate the Irrigation Management Program (IMP) with CIMIS to update irrigation schedules using current weather data and on-farm data;

4. validate irrigation scheduling information in the field with field research and obtain field data to substantiate the advantages of irrigation scheduling, such as water and energy savings, yield improvement, and salinity management;

5. evaluate grower acceptance of computer generated and delivered irrigation scheduling information; and

6. develop a statewide extension service educational program to provide growers with information on irrigation scheduling.

At the end of the project, University of California researchers will evaluate the costs and benefits to the grower of using computerized irrigation scheduling information. On the basis of the evaluation, the University will recommend whether CIMIS should be continued.

Cost of Irrigation Scheduling Services. Costs for irrigation scheduling services vary considerably. Private consultant fees range from $6 to $10 per acre per year. However, some consultants have found that they cannot survive on scheduling irrigations alone. Many sell fertilizer/plant nutrition services or pest management services along with scheduling services. The advantage of multiple-service consulting to the large corporate farms is probably in water and pest management, as the fertilizer companies more readily offer soil analysis to the larger growers. The smaller growers are more apt to desire fertilizer management services (soil sampling) because they are less likely to obtain this service from fertilizer companies. The small grower is a less attractive market for the consultants; many consultants will not schedule under 1000 acres and/or use a floating fee to minimize the time/cost disparity of scheduling smaller acreages.

Large corporate farms often develop their own scheduling programs, hiring qualified technical personnel, buying equipment (computers and moisture-sensing equipment), and developing the software needed for a scheduling program. The larger the acreage, the more cost effective this approach becomes, as compared to hiring a private consultant. The cost would depend on the acreage covered and level of scheduling technology used. One corporate farm in Kern County identified the cost of its own scheduling service at about $3.33 per acre.

El Dorado Irrigation District has continued the IMS program for its growers. In 1981, the District allocated $5.88 per acre per year to finance the program. Growers do not pay directly for the service. Solano Irrigation District has also continued the IMS program, and the District is also bearing the cost of the program. The approximate 1981 cost of operation of the IMS in Solano Irrigation District was $30,000. Westlands Water District has continued IMS in a much altered form (without field monitoring) at a cost of $150,000, all borne by the District. Yolo County Flood Control and Water Conservation District was in the second year of the introductory USBR-IMS program, and charged its grower-users $1.00 per acre to cover some of the District's costs, with the Bureau paying their own costs.

Table A/1 shows the approximate costs for ISS from various sources:

Table A/1. Approximate Costs of Irrigation Scheduling Services in California

Scheduling Service by	Acres in Program	Total Costs	Cost per Acre in Program (1981)
		--------------(dollars)--------------	
Private Consultants	---	---	6-10, grower's cost
El Dorado I.D.	4,000	30,000	7.50, District cost
Solano I.D.	4,000	30,000	7.50, District cost
Westlands W.D. (Guide program)	550,000	150,000	0.27, District cost

Factors Influencing Use of Irrigation Scheduling. Tree growers tend to be somewhat more inclined to use predictive scheduling than are row crop growers. This might be because trees are deep-rooted and orchardists are more interested in knowing the water status deep in the soil profile.

Large farms are more inclined to use predictive scheduling than are small family operations. Largeness induces problems of logistics, for which ISS is an effective management tool.

Newness is often a factor inclining a grower to use irrigation scheduling. Growers managing a new crop or a new field with unfamiliar soils frequently favor the use of scheduling. ISS is also used to help solve particular field problems related to water management. Consultants are often used to help manage irrigations on soils with high salt content or low infiltration rates. Irrigation scheduling has also been helpful on soils with a high water table or with compacted layers.

Limitations of Irrigation Scheduling. When water supplies are readily available and inexpensive, a grower's incentive to adopt a scheduling program may be limited. On the other hand, even when water supplies are abundant, some growers have found that predictive scheduling can help them identify management problems, improve their overall operations, and, most importantly, reduce their total costs.

In some cases, predictive scheduling may be limited by factors beyond a grower's control. Inflexible delivery schedules may preclude irrigation at the exact time it is needed. Sprinkler systems may be incapable of delivering the recommended quantities of water. Those limitations become less important, however, with annual crops and with tree or vine crops.

Costs may also be a limiting factor. In the Westlands Water District, for example, a district-wide scheduling program would cost, at $7.50 per acre, about $4 million. The district is now attempting to develop a scheduling program at a much lower cost. However, the program is not tailored to meet the needs of individual growers, and few of them have been using it. The district has now begun a number of individual programs in an attempt to demonstrate the benefits that could result from district-wide scheduling.

Termination of the Bureau of Reclamation's IMS program in both the James and Tranquility Water districts was due to several factors. In both districts, farms are small and thus the management benefits of the program were minimized. In addition, water is plentiful, inexpensive, and sold by cropped acre thus, there was little incentive for growers to conserve water. Finally, many of the long-time growers are confident that they are producing maximum yields, and, since the IMS program resulted in only minimum benefits, it probably reinforced that belief.

What is needed in the future is more objective information on the benefits of scheduling--specifically how scheduling programs can result in lower water costs, increased crop yields, higher quality crops, on-farm water savings, and increased profits.

The IMS program in the Yolo County Flood Control and Water Conservation District has demonstrated that water use can be reduced. Specifically, the program demonstrated that sugar beets and tomatoes need only one irrigation, instead of two, prior to germination, thus saving about 6 inches of applied water. Corn was grown with one (and sometimes two), fewer irrigation than is normally applied during the season. More programs of this type would convince growers that scheduling programs can benefit them.

Improved Water Distribution Systems

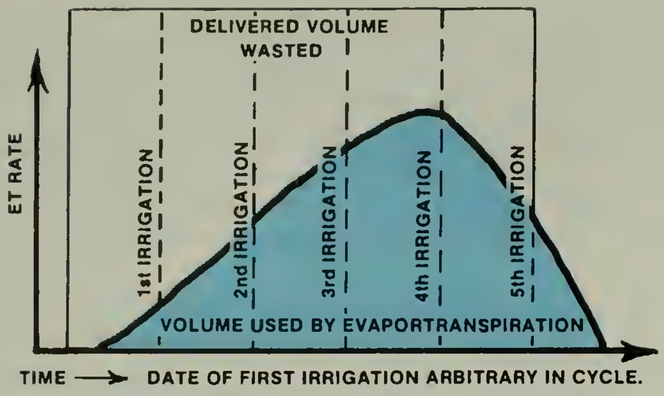
For modern irrigation scheduling to be effective, growers must be able to regulate the frequency, rate, and duration of irrigation. On-farm irrigation scheduling and techniques for better irrigation efficiencies are necessary if growers are to maximize profits. In the report Distribution Systems Improvement to Facilitate Water Delivery, prepared by J. M. Lord, Inc., for the Department's Office of Water Conservation, one conclusion was that in general, water deliveries to the farm are not sufficiently flexible or precise to permit effective application of existing irrigation scheduling technology. Accordingly, water supply agencies may have to adjust their delivery schedules so that growers will be able to apply irrigation water when it is needed.

Water District Deliveries. Most canal systems are operated under upstream control. Upstream control can be classified as a "supply" operation rather than a "demand" operation. Conventional upstream control means releasing water from an upstream source in anticipation of demand downstream. Once the water from an upstream source is released on sloping canal systems, the water must either be used or spilled at the lower end.

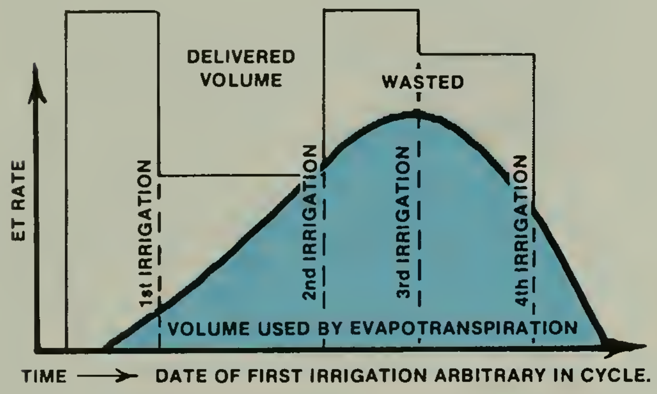
Districts generally use a rigid, predetermined supplier-controlled schedule. These rigid types of schedules usually place restrictions on the amount or frequency of water delivered and may be described as (1) constant amount, constant frequency, (2) constant amount, variable frequency, (3) varied amount, constant frequency. The schedules are planned so adequate water can be delivered to the farm when the crop's water needs are highest. To determine the proper amount of water, the interactions among the water, the soil, the plant, and the atmosphere should be known.

The first schedule, constant amount, constant frequency, generally called a rotation schedule. Without modification, it is the least expensive for canals and structures and involves the least management and operational input. The canal is always flowing at its maximum rate and can be of a minimum size. This schedule of water delivery may cause the grower to operate at the low efficiencies. Figure A/5 illustrates this schedule.

The second schedule, illustrated in the middle part of the figure, is a constant amount, variable frequency schedule. It can reduce overirrigation on the farm.



Constant Amount-Constant Frequency (Rotation) Schedule.



Constant Amount-Variable Frequency Schedule (Variable Frequency Rotation).

Figure A/5. Irrigation District's Delivery Schedule

However, with the changing irrigation interval, the management allowable deficiency of the soil moisture ideally must be the same and essentially must always be satisfied. Such a condition will not be applicable on a large number of farms, however, since it implies that all soils and root zone depths of all crops are the same everywhere throughout the season. Since the frequency is stretched out, the first person to receive water on the first round may apply too much water, and the last person may receive water too late. At the end of the schedule, the positions will be reversed. For the water agency, this schedule means that the same minimum-size ditch is usable but that it will be empty part of the season.

The third schedule, varied amount, constant frequency, shown in the lower part of the figure, can be called a varied amount rotation schedule. It still permits the water agency to use a minimum ditch. The amount of water turned into the ditch at each cycle is varied, but the canal is always in operation. Again, it is best adapted to perennial crops with uniform soils and root zone depths. Due to the short constant intervals, annual crops requiring more frequent applications early in the season may be grown successfully. However, they will be overirrigated early in the season.

Flexible Water Delivery. Flexible schedules or demand schedules are user-controlled. Compromises between the needs of the water delivery agency and the farmer will create restrictions on each that should ideally result in an optimal economical solution to delivery problems. The three key elements in the term flexibility, as defined by J. M. Lord, are:

1. Frequency. This refers to how often or at what interval an irrigation event will occur. Throughout the life of a plant, water is needed at different frequencies. For example, a young, shallow-rooted plant may need frequent, light applications.

2. Rate. This refers to the flow rate from the turnout. A farmer may irrigate several fields from one turnout, and may use surface irrigation on one field and sprinklers on another. Each method requires different flow rates, depending on field size, soil, etc. If surface irrigation is used, it may be desirable to use a cutback stream to reduce runoff, which would require a change in flow rate at the turnout.

3. Duration. This refers to the length of an irrigation event. With surface irrigation it is difficult to predict the length of time necessary for a given depth of water to infiltrate, so the supply must accommo-

date changing the duration of an irrigation to match soil intake conditions.

The flexible schedules may be defined as: (1) demand; (2) limited rate demand; (3) arranged (as to date); (4) limited rate arranged; (5) restricted arranged, in which both the rate and duration and fixed and remain constant as arranged; and (6) fixed duration, restricted arranged, in which the fixed duration is set by policy and date, and constant rate are arranged. None of these schedules imply that the volume of water may not be limited, and totalizing water meters are needed for all but 5 and 6.

The demand schedule may be considered too ideal an approach. Until the maximum desired rate exceeds the delivery capability, however, the schedule does not inhibit operations. Only when the rate becomes small enough to impede the desired operation does it need to be called a limited-rate demand schedule. These schedules place negligible restrictions on the farmer and permit him to optimize his irrigation program. They require that the peaking capacity of the system be quite large and that the system be automated, and no communication system is required. The arranged schedule may also be looked at as being too ideal, permitting as it does the selection of the day or days, usually plus or minus one day, and having no restrictions on the rate or duration. However, it, like the demand schedule, may often be attainable. The restriction of having to set a delivery date seldom causes more than a slight inconvenience for the grower and creates only a small amount of administrative work in the agency office.

The restricted arranged schedule imposes greater limitations. The delivery date can be arranged, but the rate and duration of delivery, once agreed on, cannot be changed. These conditions make the agency administration and operation simpler, since flow rates can be anticipated at any specific time. This schedule may be used as an interim step in upgrading systems. This schedule also requires the highest level of management on the part of the grower. To know what stream size and duration will be just what are needed for each irrigation is next to impossible due to the many variables involved. The only safe procedure is to order more water than is essential for a longer duration than necessary to be sure that irrigation is adequate.

The fixed-duration, restricted arranged schedule is in fairly common usage in the United States. It does not require automation or totalizing meters. The date and fixed flow rate are arranged. The duration is fixed usually at 24 hours to permit more constant flow rates. The schedule also permits ditch tenders to plan their work and reduces the number of manual changes in the flow rate. The 24-hour duration can cause difficulties in the utilization of labor. It means that water may be run too long, though occasionally it may be too short. The arranged rate, which is fixed and usually small, encourages overirrigation to be sure of adequate volume.

Table A/2 summarizes the various restrictions on each of the schedules in the order of increasing intensity. In general, the more flexible schedules controlled more by the user can result in more efficient use of water and labor on the farm and impose minimum limitations on crop selection and production.

Engineering Possibilities

There is a low level of awareness of possible engineering solutions to upgrade distribution systems. Each district has its own unique problems and solutions to its delivery problems. There are several possibilities for upgrading less flexible schedules, including total reconstruction, repair and replacement with increased capacity, adding regulating reservoirs, and using

Table A/2. Water Delivery Constraints

Schedule Name	Frequency	Rate	Duration
Demand	Unlimited	Unlimited	Unlimited
Limited-rate, demand	Unlimited	Limited	Unlimited
Arranged	Arranged	Unlimited	Unlimited
Limited-rate, arranged	Arranged	Limited	Unlimited
Restricted-arranged	Arranged	Constant	Constant
Fixed-duration, restricted-arranged	Arranged	Constant	Fixed by policy
Varied-amount, constant-frequency (modified-amount rotation)	Fixed	Varied as fixed	Fixed
Constant-amount, varied frequency (modified-frequency rotation)	Varied as fixed	Fixed	Fixed
Constant-amount, constant-frequency (rotation)	Fixed	Fixed	Fixed

Unlimited: Unlimited and controlled by the user.

Limited: Maximum flow rate limited by physical size of system or turnout capacity but causing only moderate to negligible problems in farm operations. The applied rate controlled by the user and may be varied as desired.

Arranged: Day or days of water availability are arranged between the water agency and the user.

Constant: The condition of rate or duration remains constant as arranged during the specific irrigation run.

Fixed: The condition is predetermined by the water agency.

automated level-top canals. These allow a no-flow condition to exist.

In general, a flexible delivery schedule controlled by the growers will result in more efficient use of water and labor. More flexible schedules will increase the water agency's capital costs but should decrease its management and operation costs.

Water Utilities

The advance notice required by a district for growers to receive water varies from 2 to 11 days, depending on district operations and the advance notice required by the water supplying agency. The average advance notice required by the districts is 33 hours; this should cause few problems for growers using modern scheduling techniques, except for a grower using high-frequency drip irrigation, where daily applications are needed. The rate and duration of the water delivery should be flexible in order to make on-farm irrigation practices more efficient. Delivery rates are controlled by the capacity of the district's system as well as the rate at which the district receives water from the water supplying agency.

There are a number of benefits associated with improving on-farm irrigation efficiencies. A benefit to the delivery agency is that less water need be delivered and water levels in the canals can possibly be lowered, reducing the chance of accidental spills. With high on-farm irrigation efficiencies, less gross water must be supplied to provide the net depths needed for ET and leaching requirements. For example, a crop may require a net flow rate of 5 gpm/acre for ET and leaching. If the on-farm water use efficiency is 50 percent, the gross amount of water delivered would be 5 gpm/.50 = 10 gpm/acre (to adequately irrigate the whole field). By increasing the efficiency to 70 percent the required gross will be reduced to 5 gpm/.70 = 7.14 gpm, almost a 30 percent reduction in flow rate.

APPENDIX B
WATER CONSERVATION LAWS

Water law in California has two basic principles. First, water within the State is the property of the people of California and the people have an interest in its use. Second, individuals can obtain a right to the use of that water, but that right is limited by what is reasonable and beneficial. Since 1928, the Constitutional requirement that water use be reasonable and beneficial has been the foundation for California case law and statutes concerning water conservation.

Below is an overview of water conservation laws in California including a discussion of the Constitutional requirement of reasonable and beneficial use, a description of the laws related to water conservation, and a discussion of the effect of water conservation on water rights.

The Constitutional Requirement of Reasonable and Beneficial Use

In 1928, the people of California adopted a constitutional amendment which was designed to prevent the waste of state waters and to apply the requirement of reasonable beneficial use to all water users. This amendment, now numbered Article X, Section 2, states that:

> "It is hereby declared that because of the conditions prevailing in this State the general welfare requires that the water resources of the State be put to beneficial use to the fullest extent of which they are capable, and that the waste or unreasonable use or unreasonable method of use of waters be prevented, and that the conservation of such waters is to be exercised with a view to the reasonable and beneficial use thereof in the interest of the people and for the public welfare. The right to water or to the use or flow of water in or from any natural stream or water course in this State is and shall be limited to such water as shall be reasonably required for the beneficial use to be served and such right does not and shall not extend to the waste or unreasonable method of use or unreasonable method of diversion of water. Riparian rights in a stream or water course attach to, but to no more than so much of the flow thereof as may be required or used consistently with this section, for the purposes for which such lands are, or may be made adaptable, in view of such reasonable and beneficial uses; provided, however, that nothing herein contained shall be construed as depriving any riparian owner of the reasonable use of water of the stream to which the owner's land is riparian under reasonable methods of diversion and use, or as depriving any appropriator of water to which the appropriator is lawfully entitled."

In a number of decisions, the California courts have held that <u>all</u> water rights in California are subject to the rule of reasonableness. <u>Peabody</u> v. <u>City of Vallejo</u>, 2 Cal.2d 351 (1935), is the major case which interpreted the 1928 Constitutional amendment. The decision reads in part:

> "The limitations and prohibitions of the constitutional amendment now apply to every water right and every method of diversion. Epitomized, the amendment declares:...
> 3. Such right does not extend to unreasonable use or unreasonable method of use or unreasonable method of diversion of water...The foregoing

> mandates are plain, they are positive, and admit of no exception. They apply to the use of all water, under whatever right the use may be enjoyed."

The Supreme Court has made it clear that reasonable use and beneficial use are two separate and independent requirements. For a water use to be reasonable, the water must be used efficiently to serve a beneficial purpose. A particular water use must have some minimal social utility to be beneficial. As the Court stated in the case of Joslin v. Marin Municipal Water District:

> "Article XIV, Section 3 [now Article X, Section 2], does not equate 'beneficial use' with 'reasonable use.' Indeed, the amendment in plain terms emphasizes that water must be conserved in California 'with a view of the reasonable and beneficial use thereof in the interest of people,' that the right to use water 'shall be limited to such water as shall be reasonably required for the beneficial use to be served,' and that riparian rights 'attach to, but to no more than so much of the flow' as may be required in view of such reasonable and beneficial uses.....' Thus, the very fact that a use may be beneficial to a riparian's lands is not sufficient if the use is not also reasonable within the meaning of Section 2 of Article XIV...." Joslin v. Marin Municipal Water District, 67 Cal.2d 132 (1967) (emphasis in original).

Legislative Declarations Regarding Reasonable and Beneficial Use

The Legislature has added to the law found in the 1928 Constitutional amendment. Water Code Sections 100 and 101 repeat the language of the 1928 amendment.

The Legislature has given the courts guidance on what factors should be considered in deciding whether a use is reasonable and beneficial. In 1980, the Legislature declared that the sale, lease, exchange or transfer of water or water rights, in itself, shall not constitute evidence of waste or unreasonable use (Water Code Section 1244). In the same year, the Legislature limited the impact of "local custom" on the determination of reasonableness of water uses. A few court decisions had held that water users were entitled to use water according to the general custom of the locality so long as the custom does not involve unnecessary waste. Thus, where irrigation systems in the area had conveyance losses of between 42 and 57.9 percent, a conveyance loss of 40 to 45 percent was not considered unreasonable. Tulare Irrigation District v. Lindsay-Strathmore Irrigation District, 3 Cal.2d 489, 547 (1935). Section 100.5 of the Water Code now declares that conformity of use, method of use, or method of diversion of water with local custom shall not be solely determinative of its reasonableness, but shall be considered as one factor to be weighed in the determination of reasonableness. Thus, a water user will not be required to use the most advanced water-saving technology available, but a person's will not be protected solely because neighbors are using water in a similar manner.

The Legislature has also made various declarations regarding certain uses of water. Section 1243 of the Water Code declares that the use of water for recreation and preservation and enhancement of fish and wildlife resources is a beneficial use of water. Section 5093.50 of the Public Resources Code states that the use of California Wild and Scenic Rivers is the "highest and most beneficial use, and is a reasonable and beneficial use of water within the meaning of the" 1928 constitutional amendment. Water Code Section 1242 concerning conjunctive use of ground water declares that the underground storage of surface water constitutes a beneficial use if the water stored is later supplied to the purpose for which it was appropriated. Additionally, a reduction or cessation in the extraction of groundwater and the use of an alternate, non-tributary source is a reasonable and beneficial use (Water Code Sections 1005.1, 1005.2, and 1005.4). The Legislature has also declared that the use of potable domestic water for the irrigation of greenbelt areas (such as cemeteries, parks, and golf courses) is a waste and unreasonable use of water when reclaimed water which meets certain conditions is available for use (Water Code Section 13550).

Court Determinations of Reasonable and Beneficial Use

The courts have generally dealt with the issues of reasonable and beneficial use on a case by case basis. Courts have found that the use of water to deposit rock and gravel for commercial purposes (Joslin v. Marin Municipal Water District, 67 Cal. 2d 132 (1967), the use of water for military purposes (United States v. Fallbrook Public Utility District, 165 F. Supp. 806 (S.D. Cal. 1958), and the diversion of water for frost protection (People ex rel. State Water Resources Control Board v. Forni, 54 Cal. App.3d 743 (1976) were all beneficial uses, but not necessarily reasonable uses under the circumstances.

In determining what is reasonable and beneficial, courts look at various factors. One consideration is what is reasonable at the time. Changed conditions may make what was once a reasonable and beneficial use a waste of water at a later time. Tulare Irrigation District v. Lindsay-Strathmore Irrigation District, supra.

Public interest has also been part of the courts' consideration. In Peabody v. City of Vallejo, supra, the court denied a riparian the right to the undiminished flow of the stream, saying "When the supply is limited public interest requires that there be the greatest number of beneficial uses which the supply can yield." 2 Cal.2d 351, 361(1935). In considering the public interest the courts have noted that the prosperity of the State depends upon conservation of the waters of the State. Gin S. Chow v. City of Santa Barbara, 217 Cal. 271 (1933). The courts may also look to the relative public interest involved in two competing interests. For example, in Joslin, supra, the court seems to have compared the public interest in municipal water uses to the public interest in the use of the water for amassing sand and gravel for a commercial use.

The case of Environmental Defense Fund v. East Bay Municipal Utility District raised important questions on the scope of Article X, Section 2 of the California Constitution. This case has been heard twice by the California Supreme Court and it is still in litigation. The plaintiffs alleged that the defendants would be violating the requirement of reasonable use of water by (1) not first reclaiming its waste water to aid in supplying its water requirements; and (2) by contracting with the U. S. Bureau of Reclamation to divert its supplemental water supply from the Folsom South Canal rather than downstream from the Sacramento River which would permit the use of water in the lower American River, for fish and wildlife maintenance and recreational purposes.

In a decision issued in 1977, the California Supreme Court agreed that the question of whether available economic resources should be devoted to waste water reclamation or to development of other water supplies did involve consideration of the reasonableness of the use. Environmental Defense Fund, Inc. v. East Bay Municipal Utility District 20 Cal.3d 327 (1977). However, the court held that the issue should not be before the courts until the administrative agencies, primarily the State Water Resources Control Board, had addressed the question.

The Environmental Defense Fund case clarified two other issues relating to reasonable and beneficial use. One of those deals with the issue of federal preemption. The other deals with the question of whether Article X, Section applies where one of the parties does not claim a traditional water right to the use of the water being contested. In its decision in 1977, the California Supreme Court had held that the plaintiffs could not challenge the construction of a dam and canal or the point of diversion of water for being in violation of State law, including Article X, Section 2, when the project in question was one authorized by federal law. The United States Supreme Court sent the case back to the California courts for reconsideration following its decision in California v. United States, 438 U.S. 645 (1978) that California may impose any condition not inconsistent with congressional directives. Thereafter, the California Supreme Court found that the plaintiffs could not challenge the construction of the dam and canal on state law grounds, but they could challenge the diversion point as an unreasonable method of diversion. Environmental Defense Fund, Inc. v. East Bay Municipal Utility District, 26 Cal.3d 183 (1980). The court held that courts could exercise concurrent jurisdiction with the State Water Resources Control Board in this type of case. Additionally, the court made it clear that one does not have to be a competing water user to ask the court to consider the reasonableness of a use under Article X, Section 2.

In another recent case, the Supreme Court reaffirmed the rule with regard to riparian rights and found that in certain cases, the amendment allows the State Water Resources Control Board to limit and quantify future unexercised riparian rights where such an action would best promote reasonable and beneficial use. In Re Waters of Long Valley Creek Stream System, 25 Cal.3d 339 (1979). In this case the court upheld the Water Board's determination regarding all rights to the use of all waters in a stream system, noting that the determination resulted in a final and comprehensive determination in light of the requirements of Article X, Section 2.

Statutory Provisions

Article X, Section 2 states that it "shall be self-executing, and that the Legislature may also enact laws in furtherance of the policy" contained in the section. In most of the cases discussed above, it has been the courts who have enforced the proscriptions against unreasonable use of water. However, administrative agencies also implement the constitutional mandate.

The Legislature has enacted a number of provisions empowering agencies to carry out the policy found in Article X, Section 2. These operate through the authority of the State Water Resources Control Board to issue permits and licenses, the authority of the Board and the Department of Water Resources to prevent waste, unreasonable use, unreasonable method of use and unreasonable method of diversion of water, and the authority of governmental agencies to implement water conservation plans.

Permits and Licenses

A significant proportion of water rights held or likely to be obtained are subject to the statutory appropriation process. This means that one must apply to the Water Board for a permit or license for the use of water (Water Code Sections 1200 et seq). The statutory scheme for the appropriation of water and the determination of water rights are declared to be in furtherance of the constitutional policy of reasonable and beneficial use (Water Code Section 1050).

One of the threshold determinations with regard to an application for a permit is that the use applied for must be for some useful or beneficial purpose (Water Code Sections 1240 and 1375 and 23 Cal. Admin. Code Section 655). In acting upon applications, the Water Board must consider the relative benefit of all beneficial uses of water and the reuse or reclamation of the water sought to be appropriated (Water Code Section 1257). The Board has been given extremely broad powers under its mandate to consider the public interest. It must reject an application if it would not conserve the public interest and it may subject an appropriation to such terms and conditions as it determines would "best develop, conserve, and utilize in the public interest, the water sought to be appropriated." (Water Code Section 1255 and 1257.) Board regulations provide that the amount specified in an application will be reduced to the extent that there is reused or reclaimed water available (23 Cal. Admin. Code, Section 654.4).

The Water Board may still exercise authority with regard to conserving water even after an applicant has obtained a permit. First, the Board may reserve jurisdiction over a permit under Water Code Section 1394 if the Board finds that there is not enough information available to determine whether the use of the water will result in a waste of water or whether the use of water will be in the best public interest or if it finds that the application is part of a coordinated project for which other applications are pending. Reserved jurisdiction is to be limited only to a time period found "reasonably necessary" and cannot be exercised after the issuance of a license.

Second, the Water Board may revoke the permit if the water is not applied to beneficial use as contemplated in the permit, the statute, and the rules and regulations of the Board (Water Code Section 1410). The Board may also take other "appropriate" action if any permit terms or conditions, including those relating to water conservation, are violated (23 Cal. Admin. Code, Section 764.6). Recently, the Board was given the authority to order any person violating any term or condition of a permit or license to cease and desist from such violation (Water Code Sections 1831-1850).

In addition, the Water Board has taken advantage of its authority to condition permits by adopting broad permit term which allow it to have continuing authority to prevent the waste, unreasonable use, unreasonable method of use or unreasonable method of diversion of water. See for example Cal. State Water Rights Board, Decision No. 869 at page 26 (February 7, 1957) and Cal. State Water Resources Control Board, Decision 1404 at page 9 (November 2, 1972). The Board authority over licenses is similar to that described above for permits (Water Code Sections 1600, 1605, 1627 and 1675). When construction of the diversion or impoundment is complete and the water is being used to the extent contemplated, the permittee may apply to the Board for a license. A license has no time limit and will continue as long as proper use is made of the water.

Additional State Administrative Authority

In addition to the permit enforcement mechanisms, the Department and the Water Board are required by Water Code Section 275 to prevent the waste and unreasonable use of water. Water Code 275 states that:

"The Department and the Board shall take all appropriate proceedings or actions before executive, legislative or judicial agencies to prevent waste, unreasonable use, unreasonable method of use, or unreasonable method of diversion of water in this State."

The section imposes upon the Department of Water Resources and the Board a mandatory duty to prevent unreasonable use of water. It extends to all water users regardless of the user's claim of right. The Board's authority under this section to seek injunctive and declaratory relief regarding direct diversion of water by riparian land owners was sustained in People ex rel. State Water Resources Control Board v. Forni, 54 Cal. App.3d 743 (1976).

The Department and the Water Board have issued joint regulations on the manner in which they will implement Water Code Sections 100 and 275. Upon request of the Board, or upon its own motion, or upon good cause shown by any interested person, the Department will investigate the misuse of water. If the Department has a contractual or other interest in the specific case, the Board may supervise the Department's investigation or conduct its own.

If the preliminary investigation indicates that water is being misused, the Department will contact the responsible party. If, within a reasonable time, the responsible party fails to demonstrate that there is no misuse occurring and the misuse is not corrected, the Water Board may require the Department to investigate further, or may hold a hearing on the matter.

After a hearing on the matter, the Water Board may issue an order requiring termination of the misuse. If the responsible party refuses or neglects to comply with the order, the Board may revoke the party's water right permit or license if there is one. If the party has not applied to the Board for water rights, the Board may refer the matter to the Attorney General for appropriate legal action (23 Cal. Admin. Code, Section 4000).

The Water Board and the Department have investigated various water uses under these and previous Board regulations regarding waste and unreasonable use. Board decisions have found the diversions of nonflood flow by a flood control district resulting in environmental harm and the filling of an artificial lake during a period of severe drought to constitute waste and unreasonable uses. Decision No. 1460 (October 27, 1976) and Decision 1463 (March 2, 1977). It has also found that intensified use of ground water does not constitute an unreasonable use where there is insufficient evidence to establish waste. Decision 1470 (June 16, 1977).

A more recent investigation was carried out by the Department based on allegations that there was waste and unreasonable use of water in the Imperial Irrigation District. The Department's findings were published in a report, Investigation Under California Water Code Section 275 of Use of Water by Imperial Irrigation District in December 1981. The Department found that there were various cost-effective conservation methods available, such as lining the canal. It has referred the matter to the Water Board since the District has declined to prepare the water conservation plans as requested by the Department.

Authority of Local Water Suppliers

The authority of local water suppliers to undertake water conservation measures comes from three sources: the general statutes which effect water suppliers, legislation creating the water district or the regulations of the Public Utilities Commission and the statutes which permit specific actions during times of water shortage emergencies.

In 1976, the Legislature enacted a measure which provided that any municipal water supplier of water, including private corporations:

> "...may undertake a water conservation program to reduce water use and may require, as a condition of new service that reasonable water-saving devices be installed to reduce water use." (Water Code Section 1009; see also Water Code Section 7160.5 for specific authority for municipal water districts.)

The authorizing acts of public water districts often include water conservation or waste water reclamation as purposes of the districts. In addition, public entities which supply water at retail may, by ordinance or resolution, adopt and enforce a water conservation program to reduce the quantity of water used by its customers (Water Code

Section 375 et seq.). This ordinance or resolution may, for other than agricultural water users, require the installation of water-saving devices. Violation of the ordinance or resolution is a misdemeanor punishable by a fine or imprisonment.

Approximately 400 water utilities are subject to the jurisdiction of the California Public Utilities Commission. The Commission has a great deal of authority to require these utilities to adopt and promote water conservation (Public Utilities Code, Section 761, 770).

All water suppliers are given additional authority to limit water use during times of shortage (Water Code Section 350 et seq.). The supplier may, after hearing and notice, declare a water shortage emergency and adopt regulations and restrictions on water use. The restrictions may include the right to deny applications for new or additional service connections. The supplier may disconnect service to customers who willfully violate the regulations. The regulations may remain in effect for the duration of the water shortage emergency.

The Implications of Water Conservation

Concerns about water rights may affect a water user's conservation decisions. There are several classes of water where there has been or may be some question regarding the nature of the right to the water. These include salvage water, return flow water, waste water, seepage water, and water saved through water conservation efforts. A user's decision to save water may depend upon whether his rights to water are reduced or whether someone else gets the right to the water conserved.

Salvage Water

Salvage water are waters of a stream or other water source that have been unavailable, as far as any beneficial use is concerned to any of the established users, but are made available by artificial means. Salvage waters involve rehabilitation of existing waters unlike development waters which introduce new water into an area. Salvage waters include water saved through application of an evaporation retardant film and through removal of highly water consumptive plants. The general rule is that the person who salvages the water is entitled to use it provided that the use does not infringe upon other users.

Water saved that has never been appropriated may require an application to the State Water Resources Control Board for water pursuant to the appropriation permit process. While it is not clear that a permit is necessary, the better view is that one should be obtained. Neither the courts nor the Legislature has dealt with the priorities of a salvage right not part of a permit or license.

Return Water

A water conservation effort may reduce the amount of return flow discharged into a stream. Return water is water diverted for irrigation or other uses that returns to either the stream from which it was diverted or to some other stream. A reduction in return water results in a net water savings to the extent that there is less evapotransporation.

Return water is unappropriated water (Water Code Section 1202(d)). The typical conflict occurs when an upstream user changes his method or place of use resulting in a decrease in the amount of water which previously had flowed back into a stream to be used for downstream uses. The general rule is that both downstream appropriators and riparians have been protected where upstream diversions would have reduced the amount of return flow previously available to downstream users. Scott v. Fruit Growers Supply Co. 202 Cal. 47 (1927) and Southern California Investment Co. v. Wilshire, 144 Cal. 68 (1904).

There are several exceptions to the general rule. Neither downstream riparians nor appropriators can claim a superior right to the return flow over an importer of foreign water (i.e. water coming from sources outside the watershed) where the water is recaptured within the importer's irrigation works or on its lands. City of Los Angeles v. City of San Fernando 14 Cal.3d 199 (1975). Also, if water is transferred through a watercourse with the intention of recapture, the transferor will not lose return flow rights to one who holds prior rights to the natural flow of the stream. Wutchumna Water Co. v. Pogue, 151 Cal 105 (1907), City of Los Angeles, supra and Water Code Section 7075.

Waste and seepage waters can also be recaptured. These waters can be distinguished from return waters in that they do not reach the watercourse and cannot be diverted from the stream by downstream users. The general rule with regard to such waters is that the owner of the land upon which they occur is not required to continue the conditions which produced such waters. Joerger v. Pacific Gas and Electric Co., 207 Cal. 8 (1929). Thus, there are no restrictions on the conservation of waste and seepage water.

Reclaimed Water

Pursuant to a legislative mandate, the Department has conducted studies and investigations on the availability and quality of waste water. The Department also considers the opportunities for reclaiming the waste water and putting it to beneficial use (Water Code Section 462 et seq.). As the technological advances for reclaiming waste water increased its attractiveness as a source of water supply, the issue of who has the right to waste water effluent had to be resolved. In most cases, if the water were not treated, it would have been discharged to a stream.

The Legislature addressed this issue in 1980. Water Code Section 1210 provides, absent an agreement to the contrary, that the owner of a waste water treatment plant shall have an exclusive right over the water reclaimed as against anyone who has discharged the water into the waste water collection and treatment system. Section 1211 provides that prior to making any change in the point of discharge, place of use or purpose of use of treated waste water, the owner of the waste treatment plant shall obtain the approval of the State Water Resources Control Board under procedures contained in the appropriative rights statute. Finally the Board cannot grant a permit or license for the reclaimed water if it was discharged into the water course with the stated intent of preserving or enhancing an instream beneficial use (Water Code Section 1212).

The legislative program for waste water reclamation includes the Water Reclamation Law (Water Code Section 13500 et seq) and the Waste Water Reuse Law (Water Code Sections 460-464). These sections provide a state policy favoring waste water reclamation, authorize a loan program for development of waste water reclamation facilities, establish procedures for health regulation of waste water reuse, grant the Department of Resources responsibility for surveys and investigations regarding waste water use and establish a comprehensive system of reporting and enforcement. Water Board regulations include consideration of waste water reclamation in the appropriative rights permit process. Among other things, the Board may require adoption of a waste water reclamation program (23 Cal. Admin. Code, Section 761(a) or may reduce the amount of water specified in an application or permit where there is a reasonable waste water reclamation alternative (23 Cal. Admin. Code, Section 654.4). (See also 23 Cal. Admin. Code, Sections 764.9 and 783.)

Conserved Water

The effect which water conservation has on a user's right depends on the type of water right held.

In the past, water conservation efforts by those holding appropriative rights may have been discouraged by the "use it or lost it" element of an appropriative right. If an appropriator does not put the entire amount of water appropriated to use, the appropriator never perfects the right to the unused water (Water Code Sections 1225, 1397). Also, the appropriator is in danger of forfeiting the water right, or a portion of it after a five year period of nonuse (Water Code Section 1241; the five year period was extended from three years in 1980).

The Legislature has recognized that the forfeiture principle could be a deterent to water conservation. In 1979, Water Code Section 1011 was enacted to provide that when an appropriator does not use any or all of the water held under the right due to water conservation efforts, the person's right will be protected to the extent of such reduction. The statute expressly states that water conservation includes not using water appropriated for irrigation purposes because of land fallowing or crop rotation. Additionally, in 1978, the Legislature enacted a law which provided that reclaimed or polluted water used in lieu of appropriated water would not reduce the appropriative right (Water Code Section 1010).

A riparian right holder has the right to a reasonable share of the water needed for his land which is adjacent to the waterway and within the watershed. A riparian right cannot generally be lost through nonuse so water conservation efforts do not jeopardize a riparian's rights. However, a court may quantify a riparian's entitlement as a part of a comprehensive adjudication of a stream system.

Groundwater rights are unquantified in the major agricultural areas of California. In the absence of statewide groundwater legislation, the courts have developed a groundwater allocation rule called correlative rights. This rule of law gives pumpers the right to a reasonable share of the water in the ground water basin for use on their overlying land. This right exists whether or not the overlying landowner has pumped water in the past. Thus, reduction in use by an overlying owner would not threaten the basic right. Non-overlying users can use any surplus water. However, these rules do not apply if the groundwater basin has been overdrafted and there is an adjudication of the rights of the users.

There are statutory provisions on groundwater pumping which are designed in part to encourage conjunctive use and protect groundwater rights. A groundwater pumper who pumps less and uses water from an alternative nontributory source, including water conservation efforts, does not diminish the right to the amount of groundwater which is being replaced with surface water (Water Code Sections 1005.1, 1005.2 and 1005.4).

The uncertainty of groundwater rights and the problems inherent in a "common pool" resource may discourage conservation. The problem with a common pool resource like groundwater is that the benefit to an individual in pumping additional water almost always outweighs the harm resulting from a slightly lower groundwater table. Particularly in overdrafted basins the crucial factor in a decision to conserve will usually be escalating cost of energy for groundwater pumping.

Water Transfers

Water transfers relate to water conservation because freer transferability of water should result in a greater efficiency of water use. A water user might decide to install a water-conserving irrigation system if the water no longer needed could be sold to another person. In the past, uncertainty over water rights has made many water users reluctant to consider selling or leasing their water or rights to water to another user. To the extent that water and water rights are secure, transfers between users become more feasible.

The Governor recently signed a bill permitting water and any type of water right to be transferred if the water use has been reduced or ceased because of the substitute use of reclaimed or waste water (Water Code Section 1010). Additionally, the law now permits the transfer of appropriated water and an appropriative water right if the use has ceased or been reduced because of water conservation efforts (Water Code Section 1011). These transfers must be undertaken pursuant to the provisions of law governing transfers.

It is the established policy of the State of California to encourage the voluntary transfer of water and water rights (Water Code Section 109). The Legislature has specifically stated that transfer of water or water rights does not, in itself, constitute evidence of waste or unreasonable use, method of use or method of diversion (Water Code Section 1244). Under legislation passed in 1982, any regional or local public agency authorized to serve water may now transfer surplus appropriated water to users outside its boundaries (Water Code Sections 380-387). Also, any appropriated water may be transferred if the agency and individual water users and right holders agree. The State Water Resources Control Board may approve change petitions associated with the transfer if it finds that there will be no unreasonable effect on fish, wildlife or other instream beneficial uses and the transfer will not unreasonably affect the overall economy of the area from which the water is being transferred. A transfer arranged under this legislation may not exceed seven years unless the water being transferred is made available as a result of waste water reclamation, the development of additional supplies or water conservation. The consent of the agency serving the intended recipient must be obtained prior to transfer.

Appropriated water is the easiest to transfer because the water right is recorded and the Legislature has established procedures for transferring appropriative rights. The transferor must comply with the applicable provisions of water law governing a change in the purpose of use, place of use and point of diversion. The Water Board may approve a transfer if it is in the public interest and there is no injury to other water users (Water Code Section 1702). In instances where the possibility for injury to other users is unknown, the Board may authorize a trial transfer not to exceed one year in order to judge the effect of the transfer (Water Code Section 1735). The Board may modify or revoke the trial transfer if it determines that the transfer will result in substantial injury to any water user. The Board also has the authority to approve long term transfers (Water Code Section 1737 et seq.).

Institutional Methods for Encouraging Water Conservation

Tax Incentives

Several water conservation measures have been instituted by the Legislature in recent years which provide tax benefits. These measures include tax credits until the year 1985 on water efficient irrigation equipment (Rev. and Tax Code Sections 17052.7 and 23602), tax credits until the year 1983 for water conservation systems, including rainwater and greywater cisterns, the replacement and modification of toilets and the installation of flow-reducing devices (Water Code Section 470 and Rev. and Tax Code Sections 17052.8), tax credits for numerous energy conserving measures, including installation of low flow showerheads (Rev. and Tax Code Sections 17052.8, 17208.7, 23601.5, and 24349.7).

Building Code Standards

In 1982, the Legislature enacted a measure requiring low flush toilets and urinals in virtually all new buildings (Health and Safety Code Section 17921.3). This is an expansion of earlier legislative restrictions on the installation of water-inefficient toilets in California. Additionally, the Energy Commission has adopted appliance efficiency standards which specify the maximum flow rate of all new showerheads, lavatory faucets and sink faucets (20 Cal. Admin. Code 1604(f)). The State Building Code requires compliance with these standards (24 Cal. Admin. Code 2-5307(b)).

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CONVERSION FACTORS

Quantity	To Convert from Metric Unit	To Customary Unit	Multiply Metric Unit By	To Convert to Metric Unit Multiply Customary Unit By
Length	millimetres (mm)	inches (in)	0 03937	25 4
	centimetres (cm) for snow depth	inches (in)	0 3937	2 54
	metres (m)	feet (ft)	3 2808	0 3048
	kilometres (km)	miles (mi)	0 62139	1 6093
Area	square millimetres (mm^2)	square inches (in^2)	0 00155	645 16
	square metres (m^2)	square feet (ft^2)	10 764	0 092903
	hectares (ha)	acres (ac)	2 4710	0 40469
	square kilometres (km^2)	square miles (mi^2)	0 3861	2 590
Volume	litres (L)	gallons (gal)	0 26417	3 7854
	megalitres	million gallons (10^6 gal)	0 26417	3 7854
	cubic metres (m^3)	cubic feet (ft^3)	35 315	0 028317
	cubic metres (m^3)	cubic yards (yd^3)	1 308	0 76455
	cubic dekametres (dam^3)	acre-feet (ac-ft)	0 8107	1 2335
Flow	cubic metres per second (m^3/s)	cubic feet per second (ft^3/s)	35 315	0 028317
	litres per minute (L/min)	gallons per minute (gal/min)	0 26417	3 7854
	litres per day (L/day)	gallons per day (gal/day)	0 26417	3 7854
	megalitres per day (ML/day)	million gallons per day (mgd)	0 26417	3 7854
	cubic dekametres per day (dam^3/day)	acre-feet per day (ac-ft/day)	0 8107	1 2335
Mass	kilograms (kg)	pounds (lb)	2 2046	0 45359
	megagrams (Mg)	tons (short, 2,000 lb)	1 1023	0 90718
Velocity	metres per second (m/s)	feet per second (ft/s)	3 2808	0 3048
Power	kilowatts (kW)	horsepower (hp)	1 3405	0.746
Pressure	kilopascals (kPa)	pounds per square inch (psi)	0 14505	6 8948
	kilopascals (kPa)	feet head of water	0 33456	2 989
Specific Capacity	litres per minute per metre drawdown	gallons per minute per foot drawdown	0 08052	12 419
Concentration	milligrams per litre (mg/L)	parts per million (ppm)	1 0	1 0
Electrical Conductivity	microsiemens per centimetre (uS/cm)	micromhos per centimetre	1 0	1 0
Temperature	degrees Celsius (°C)	degrees Fahrenheit (°F)	(1 8 × °C)+32	(°F−32)/1 8

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